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HOLOGRAPHIC INTERFEROMETRY OF CFRP WING TIPS. (U)
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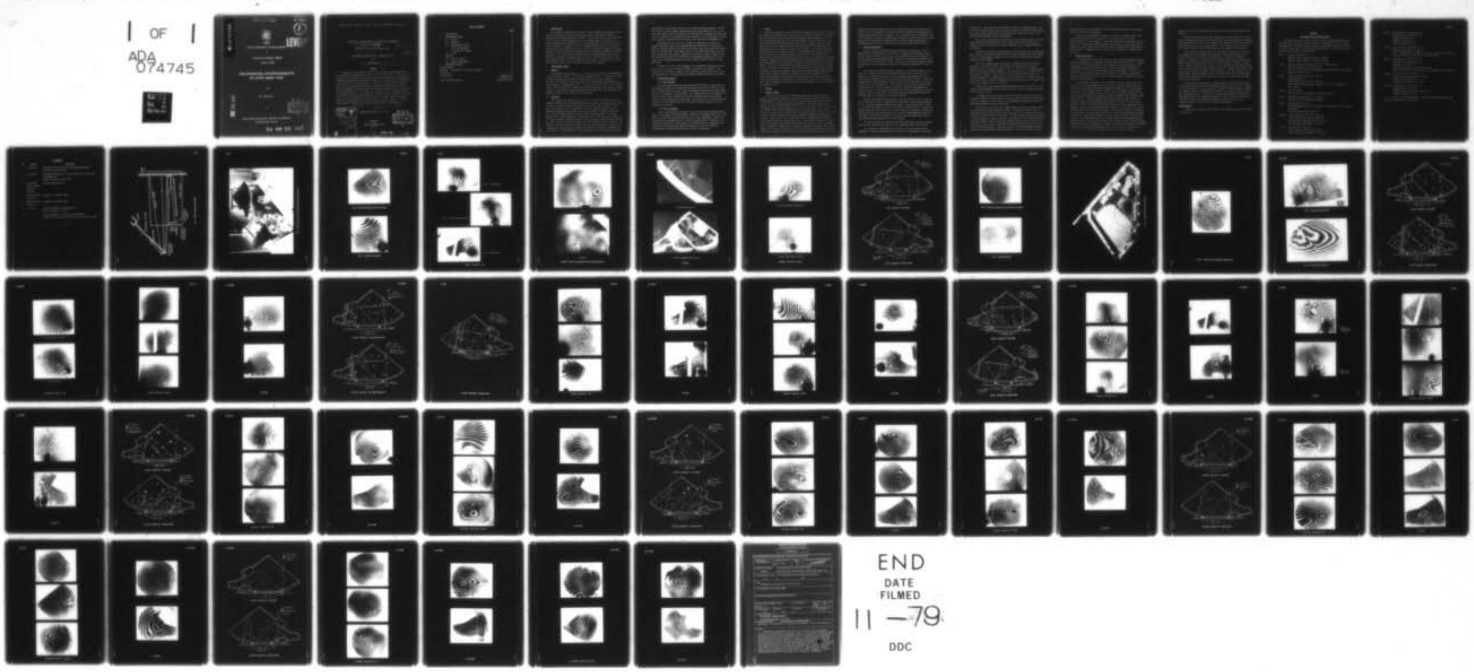

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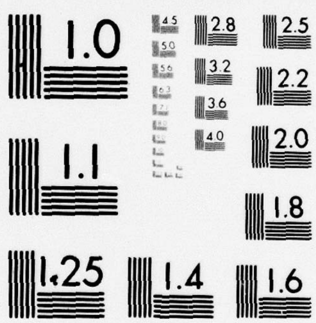

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Technical Report 78105

August 1978

HOLOGRAPHIC INTERFEROMETRY OF CFRP WING TIPS

by

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(6) HOLOGRAPHIC INTERFEROMETRY OF CFRP WING TIPS.

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SUMMARY

Holographic interferometry has been used to examine seven experimental Harrier ferry-tips primarily for defects in core to skin bonding. With increasing experience, the quality of the holograms recorded has improved, and although the interference patterns formed when the structure is warmed are often complicated, discontinuities are readily observed. A number of suspected defects have been found which are virtually undetectable using standard radiographic techniques. The most prominent of these are the long straight anomalies visible on all but the first sample examined; it is thought that they may be due to overlapping sheets of film adhesive but this has not yet been established with certainty. An ultrasonic scan of one sample also failed to detect it. Small circular patterns, possibly indicating debonds, have been found in a number of places. A group of large anomalies observed on one sample were confirmed by radiography.

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1 INTRODUCTION

The testing of carbon-fibre reinforced plastic wingtips by holographic interferometry followed preliminary trials using specially made panels of similar construction containing artificial 'defects'. This work, which is fully described in Refs 1 and 2, showed holography to be a promising method for testing quite large components and demonstrated that at least some types of skin debonds could be readily detected. The work is part of a programme being carried out to find the most suitable test-method and the results will be assessed and compared with those obtained by various alternative techniques such as ultrasonic scanning and acoustic emission. It is expected that intercomparison of the photographs obtained will permit the detection of anomalies even in the more complicated patterns. It has been suggested[3] that it will be possible in due course, to strip the skins of one or more tips and thus reveal the causes of the observed anomalies.

2 EXPERIMENTAL DETAIL

2.1 Wingtip

The wingtips measure some 2 m by 1 m overall with a thickness varying between a few mm and about 100 mm[4]. The skins are composed of up to 11 laminae, each about 0.125 mm thick, giving a maximum thickness of about 1.4 mm and a minimum of 0.37 mm[5]. The framework is of titanium and the resinated paper honeycomb core has a cell diameter of approximately 5 mm. For the tests, the surface was sprayed with a thin layer of whitewash to remove any specular reflections and to improve fringe contrast. Earlier work[1] on the sample panels had proved that such a layer had no significant effect on the behaviour of the surface.

2.2 Apparatus

The layout of the apparatus used for Nos 4, 6 and 8 is shown in Fig 1; the wingtip, reference mirror and hologram plate were mounted on one heavy steel table, the laser on another and the beam expander and spatial filter, together with a small adjustable mirror were supported on a third. Wherever possible the components were magnetically clamped to the table; elsewhere very heavy stands were used, generally with magnetic stops to prevent sideways movement. The centre height of the optical equipment was kept down to 18 cm above the table. Since, in the space available, the maximum diameter of the spatially filtered object beam was only about 75 cm, the adjustable mirror was used to examine various sections of the wingtip. A small part of the incident beam was used to provide the reference, the 'common-path' layout helping to minimise the effects of extraneous vibration and air currents. A suitable object-to-reference beam ratio[1] was obtained by careful

positioning of the reference mirror in the Gaussian illuminating beam. For the later tips, the whole system, including the laser, was mounted on a 2.4 x 1.2 m vibration isolated table and stability was much improved, although the tips proved to be very sensitive to airborne noise and vibration. The set-up, shown in Fig 2, used a separate reference beam from a mirror just outside the illuminated area.

The mounting of the tip itself, though not completely satisfactory as regards stability, caused fewer problems than had been feared. A heavy steel frame was clamped rigidly to one end of the surface table and braced with scaffold poles to the other end. The wingtip rested on two small steel rollers, and was held back against three 'point' supports on the frame by means of elastic cords. The tightness and position of these cords was determined largely by trial and error, and a sufficiently stable set-up was usually achieved without too much difficulty.

In tests after tip 8, the arrangement of the apparatus allowed the adjustable mirror to be used to provide a degree of control of the pattern[6]. The fringes could be altered in spacing and orientation, so that some of the 'whole body' movement could be cancelled out and smaller anomalies detected more easily.

2.3 Photographic details

2.3.1 The holograms

A continuous-wave argon-ion laser giving 500-1000 mW in a single mode at a wave-length of either 514 or 488 nm was employed, and except for the very early work when Kodak 649F plates were used, the holograms were recorded on Agfa 10E56 plates, with exposures of $\frac{1}{2}$-$3\frac{1}{2}$ seconds. The average density of the holograms for the first three tips was around 0.5, giving a reasonably good reconstruction without too much attenuation of the scene. For the last four tips the plates were bleached in a ferricyanide solution so that much brighter pictures of the live fringes were obtained.

2.3.2 The live fringes

In most cases these were recorded on Ilford FP4 film ($\frac{1}{8}$-$\frac{1}{2}$ second exposure) using a 35 mm single lens reflex camera. Some cine recordings (Ilford Mk V 16 mm film, 10-12 fps) have also been made as well as video recordings. Some of the former have been incorporated into a short film made by RAE to demonstrate the technique and also into a film[7], made by the Central Office of Information in conjunction with the National Physical Laboratory, as one of a number of illustrations of applications produced by various laboratories.

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2.4 Stress

The stress required to cause differential movement of the surface at defective points was not known and so the tests were carried out using 'live fringes'[1], the tip being thermally stressed after recording the datum hologram. For tip 4 heat was generally applied to the rear (non-viewed) surface by means of a 1 kW radiant heater placed centrally about 45 cm from the surface. Tip 6 was first heated from the rear using a small hot-air blower some 20 cm distant and moved continuously over the surface to avoid local hot spots. If no faults were seen, the front surface was similarly heated. Front heating with the blower was used exclusively for tip 8, and both methods for tips 10-14. The patterns were observed not only during the heating but also for some time afterwards and on many occasions, especially after front heating, better pictures were obtained during the cooling period. This confirmed the results of the previous work on the test panels. It should be mentioned that limited heating was the only type of stress available for these tests and there was little control over how much was applied. In general, heating was continued until the gross surface movement became excessive and the fringes disappeared. However, this occurred unevenly over the section being examined, and especially in outer areas might well have happened before any differential movement due to faults could be detected. On the other hand, once an anomaly had been seen it was always possible to cause it to reappear in subsequent tests.

3 RESULTS

3.1 General remarks

In the very early work, the holograms obtained were often not of good quality; the fringes tended not to be located on the tip surface (and were often 'beyond infinity' as seen in the camera), the focus varied across the field of view and was not constant during the observations. All these problems were thought to be due to instability of the set-up and especially to the long exposures (15 seconds) needed for the Kodak plates in use at that time. Later, as the stability of the set-up was improved and the hologram exposure reduced to a second or less by using the faster Agfa plates, successful holograms were generally obtained. However, there were always some failures, probably due to movement of the tip itself caused by airborne vibration. It was noticed during tests on the later tips, mounted on the vibration-isolated table, that even the live fringes could be completely 'washed-out' by passing helicopters for example, whereas heavy impacts on the floor had no effect. Care had to be taken when fixing the elastic cords not to introduce local strains at the rear mounting points, since this could

introduce misleading fringe patterns; the large distortion in the fringes on the right in Fig 3 corresponded to the position of such a point, and disappeared completely when the cords were readjusted. With a structure such as the wingtip, the patterns formed are naturally complicated, particularly around joints in the framework, which itself produces discontinuities. However, major faults should be distinguishable, since very similar basic patterns are recorded for each tip.

3.2 Typical photographs

Some of the more interesting patterns recorded are given here. A more detailed set of photographs will be found in the Appendix; these show as far as possible typical results for the whole of each surface of the seven wingtips but in a few cases the photographs were not suitable for reproduction and most of the top of tip 4 was recorded only on tape. However, all areas were examined visually at least once, and on occasions the period of observation extended over a day or more.

Fig 4 shows two prominent anomalies detected on the bottom surface of tip 6. These are, firstly, a part of the straight line seen on all but the first tip examined, and running horizontally in the photograph, and secondly an area of rather jagged fringes on the left, quite unlike any other area seen. It has been suggested that the latter might be caused by poor skin quality and the former by an overlap in the film adhesive. It was visible on both top and bottom surfaces in the same position on the wingtip, and was not revealed by radiography nor ultrasonic scan. A very minor discontinuity for which no explanation is available appears at 60° to the main line; the large pattern at bottom right behind the reference mirror corresponds to the internal framing.

Figs 5a-c show the results obtained on the top surface of tip 8. This tip was received direct from the manufacturers and had had no previous tests applied to it. Some very prominent anomalies were found in all areas as well as traces of a straight line (above '10' and '15') similar to that on tip 6. It seemed just possible that this line might be due to some strain in the mounting, although the earlier tests had involved relocation, so a series of photographs was taken with the support rollers lower relative to the 3-point mount and then with the tip tilted through approximately 12° in each direction.

The typical results of Figs 6a&b show that, within the accuracy of observation the line remained fixed relative to the reference numbers in all cases.

The wingtip was radiographed in an attempt to find the cause of these anomalies. A typical result is given in Fig 7a and a rough mosaic of the whole 1C

tip in Fig 7b. Agreement with the holographic results is remarkably good. All the 'faults' shown in Fig 5 (and two others, thought to be nearer the bottom skin) can be seen with the exception of the straight line. These two 'faults' were detected holographically later (see Appendix).

The set-up for examining the bottom surface was extremely stable and it was noticed that after some hours more skin laminae could be seen (Fig 8a is an example) and that later still the fringes developed a very irregular appearance (eg Fig 8b).

Fig 9a&b are sketches to show mountings, reference marks, and all anomalies seen. These include (9b) an indication of a number of laminae which were detected visually after prolonged heating of the front surface but were not photographed because of focus changes.

Tip 10 had undergone other tests before reaching us and cement patches remained on the bottom surface. The positions of three circular anomalies detected on the top surface (between '9' and '11' in Fig 10, for example) correspond to such cement patches underneath. There was no sign of a straight line in the position of those on tips 6 and 8, but a very similar effect can be seen running diagonally and roughly parallel to the internal rib. A similar line was seen on the bottom surface in approximately the same position on the wingtip; and also on both sides of tips 12, 13 and 14.

Patterns which may indicate debonding between skin and core were seen in a number of the photographs of various tips, and Fig 11 shows a typical one on the bottom surface of No 12.

A photograph (Fig 12) supplied by HSA shows this tip before the skin was attached; a number of curved lines are clearly visible in the section between the ribs, but nothing was seen of these in the holographic examination (eg Fig 12). Radiographs showed no defects of any kind.

One surface of tip 10 was also examined using a much more divergent beam so that the whole area was illuminated at once. The result is shown in Fig 13; although the major anomalies can be seen, the quality is not good enough in this particular set-up to detect fine detail. In order to obtain sufficient divergence of the illumination, a negative lens had to be added and so the beam could not be spatially filtered; there are therefore spurious patterns caused by dust etc in the optical train as well as flare from the reference mirror which could not be placed outside the picture. These were, however, purely experimental problems and could be overcome with suitable equipment. It was also difficult to avoid

large movements at the extremities of the wingtip when the centre was adequately heated to reveal the line anomaly.

Double-exposure holograms were made of tips 8 and 10 using a pulsed ruby laser giving an exposure time of 30 ns with the tips simply set up on a wooden bench with a box as support. After recording the first hologram, heat was applied for a minute or so and the surface then allowed to cool a little before making the second exposure, the total time between exposures being approximately three minutes. A typical result is shown in Fig 14, which may be compared with Fig A11c.

4 CONCLUDING REMARKS

It is apparent that some types of defect can be readily observed using holographic interferometry in conjunction with thermal stressing (eg tip 8). However, the fringe patterns produced can be very complicated, and only experience will show whether all important defects can be reliably and repeatedly detected, especially if they occur close to internal joints for example. Care must also be taken to avoid spurious patterns due to mountings. The change in underlying material might conceal an overall change in bond strength, although local debonds should be distinguishable.

The holographic technique is very sensitive, and the honeycomb cells and even the edges of skin laminae can often be seen. This very sensitivity is, in some ways a disadvantage, since minor changes, presumably not to be interpreted as defects, tend to become visible. However, with for example a predetermined stress, it would doubtless be possible to avoid or discount such changes. A number of suspected faults have been detected; they include possible debonds on the underside of No 4, the top surface of No 6 and both sides of Nos 10 and 12, a rough area perhaps indicating poor skin quality on No 6, and the very obvious anomalies of No 8, as well as various other small and so far unexplained pattern changes. The most striking discontinuities, however, are the long, more or less straight lines seen in all tips except No 4. (This was the first to be examined and it might well be that with the present more stable set-up and more prolonged heating such a line would be found.) On tips 6 and 8 the line, visible on both surfaces, runs roughly parallel to the leading edge and is in approximately the same position on each tip. On the other four, a similar line was detected running roughly parallel to the internal rib. These lines have not been found by standard radiographic procedures and ultrasonic scan of tip 6 failed to reveal such a 'defect'. It has recently been suggested that the effect is, in fact,

caused by an area of overlapping film adhesive, but this theory has not yet been verified.

It should be borne in mind when comparing the results given in this report that the experimental set-up and its detailed use have been modified and extended during the course of the work; for example, small apparent debonds can now be made more prominent by the use of fringe control[6]. The results for the later tips (10-14) may therefore be more representative of the potential of the method.

For the future, the main need is for confirmation of suspected flaws, and most especially of the straight line anomalies. Close examination of all the results should help in assessing the significance of the more complicated patterns. Stability of the set-up remains somewhat worse than we should like in spite of the vibration-isolated table; airborne vibration is probably the main cause. However, when the stress required can be specified, the double-pulse ruby laser can be used to take 'frozen fringe' exposures. Although each exposure would then be short enough to eliminate vibration entirely, the time required to heat (and probably cool) the wingtip would be relatively long, with consequent whole-body movement possible between exposures, and acoustic or mechanical stressing may prove more suitable.

A photosensitive thermoplastic recording material is now available which could replace the rather tedious photographic process and allow the live fringes to be viewed within two or three seconds of taking the datum hologram. Preliminary demonstrations of a commercially-available device using this material have given promising results. In addition, a system using electronic recording and processing designed at Loughborough University is being further developed there under MOD contract. The equipment, however, has lower resolution and is primarily intended for work in less favourable environments.

Acknowledgment

I should like to thank Mr M.P. Wright for the contribution using the pulsed laser (Fig 14).

Appendix

PHOTOGRAPHS OF ALL SEVEN WINGTIPS

This Appendix gives, as far as possible, typical photographs covering the whole area of all fourteen surfaces examined. Also given are sketches showing mounting points, reference markings and all discontinuities, except those due to the metal framing, seen in the many photographs recorded. Patterns which may be of particular interest are listed below:

Fig A3 Diagonal line left of '1'
Lines at centre left and top right of shadow.
Possible debond between '8' and cement patch.

Fig A5 Long horizontal line between '8' and '7' (second run).
Possible debond below '9' (first run).
Note: (d) and (e) are from different mounting positions and the shadow obscures different areas.

Fig A6 Long horizontal line below '3' and '8'.
Rough area near '2'.
Fine diagonal line left of '6' and '7'.
Note: the large discontinuity between '6' and '2' corresponds to a rear support.

Fig A8 See main report.
Note: shadow covers different areas in (d) and (e).

Fig A9 Horizontal line through 'E', 'J' and 'O'.
Diagonal line left of shadow in Fig A9a.

Fig A11 Line through '6' and '10'.
Possible debonds left of '8', right of '9' and right of '14'. See also main report.
Faint line between frame and '10'.

Fig A12 Vertical faint line left of 'B' and 'D'.
Various small circles left of this line.
Line parallel to frame left of 'F' and 'G'.
Faint diagonal line between 'K' and 'L'.

Fig A14 Line left of '5' and '6'.
Small variations right of this line.
Faint diagonal lines between '11' and '12'

Fig A15 Line right of 'F' and left of 'H'.
Diagonal lines left and below 'J'.
Diagonal line left of 'K'.
Diagonal line left of 'A'.
Possible debond near 'C'.

Fig A17 Line left of '6' and right of '7'.
Diagonal lines between '1' and '2'.
Note: photograph (f) was taken an hour later than (e), using fringe control to show detail left of '1' not seen earlier.

Fig A18 Line right of 'F' and left of 'J'.
Horizontal line below 'C' and 'G'.
Diagonal line left of 'L'.
Vertical line right of 'B' and left of 'E'.
Note: large pattern between 'A' and 'F' corresponds to rear support.

Fig A20 Line left of 'D', 'E' and 'F'.
Fainter line between rib and this line.
Diagonal line right of 'C'.
Diagonal lines between 'J' and 'K'.

Fig A21 Line right of 'D', 'E' and 'F'.
Diagonal line left of 'A'.
Complicated pattern on metal edge near 'A'.
Diagonal lines left of 'L'.

In addition, various skin laminae can be seen on many photographs, and others were observed but not recorded.

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2	M. Marchant	Temperature sensitivity of CFRP honeycomb structures under holographic NDT. Non-dest testing, February 1973
3	H. Rochefort Hawker Siddeley Aviation, Kingston	Private communications.
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7	-	Laser holography - a new tool for measurement. NPL-COI film, Central Film Library. Cat. No UK 3201 (1973)

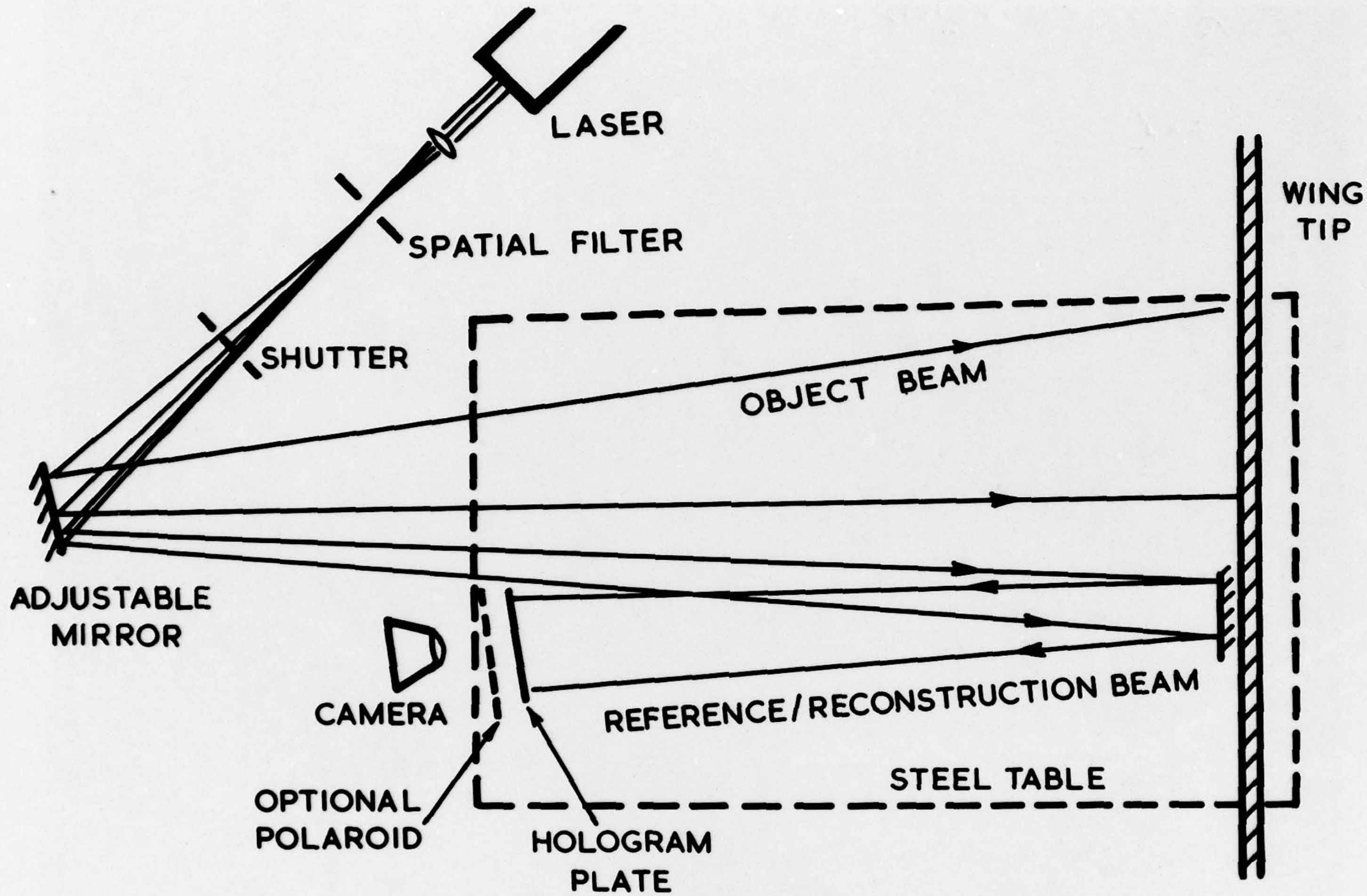


Fig 1 Layout of apparatus (tips 4-8)

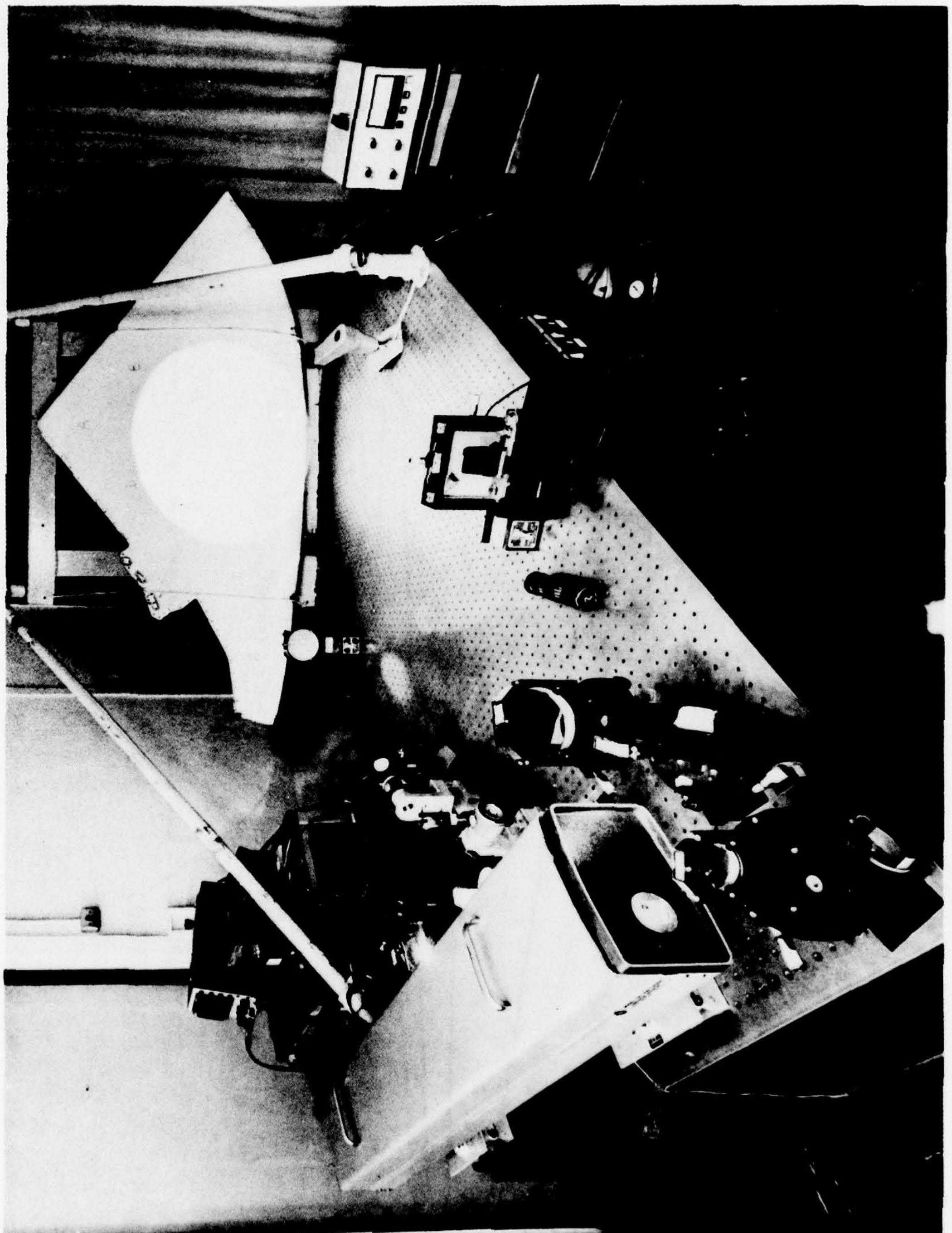


Fig 2 Set-up for wing tips 10-14 showing mounting of wing tip

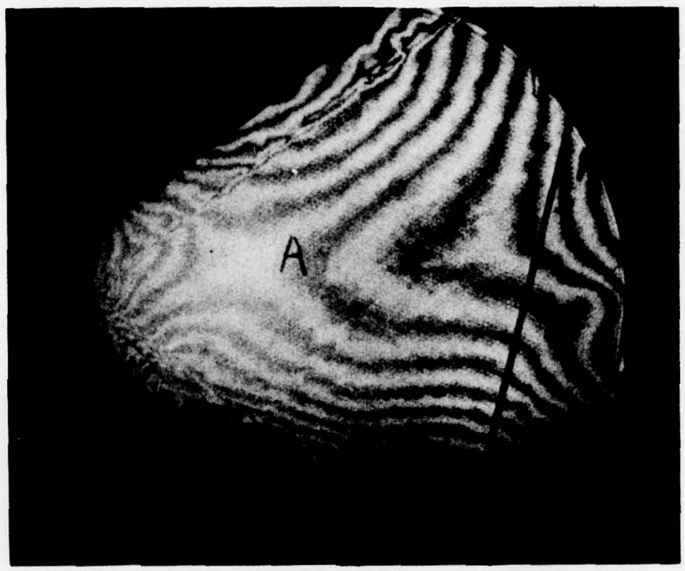
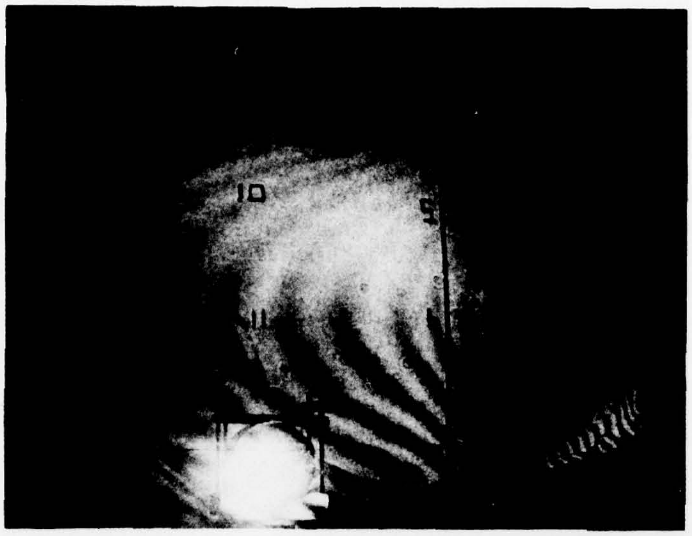
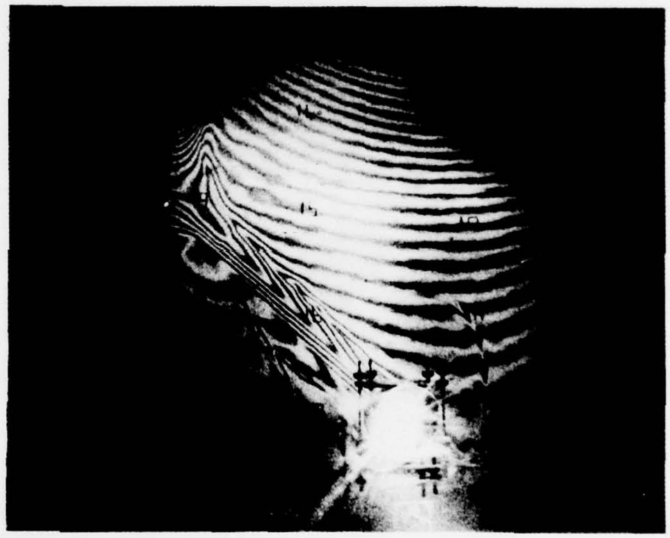


Fig 3 *Distortion* caused by strain in mounting

Fig 4 Anomalies in wing tip 6



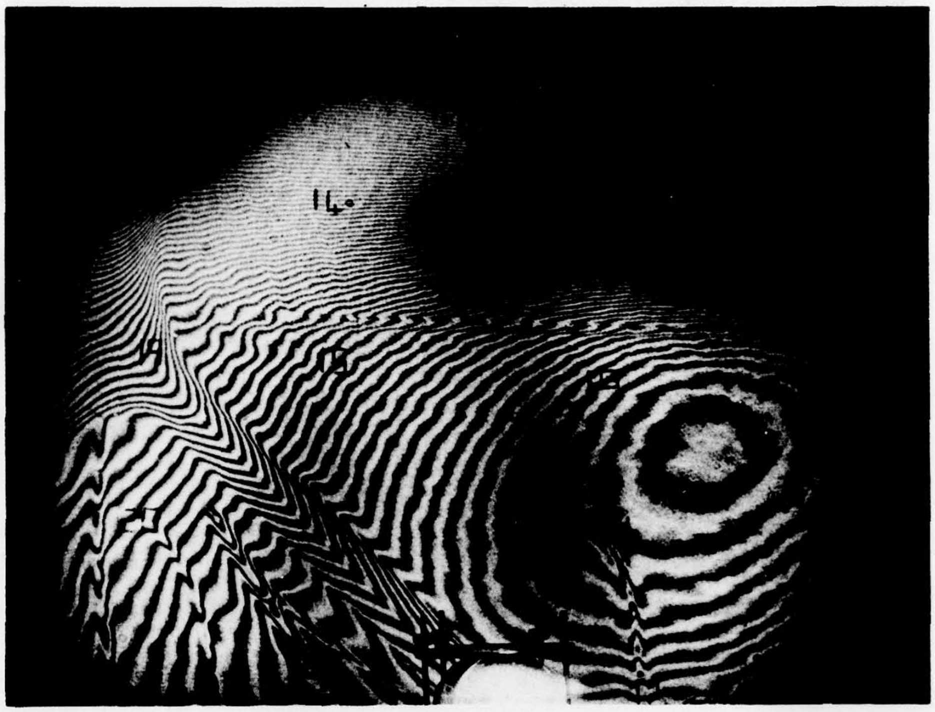
a Area 1 – various anomalies



b Area 2 – various anomalies including line

c Area 3 – various anomalies

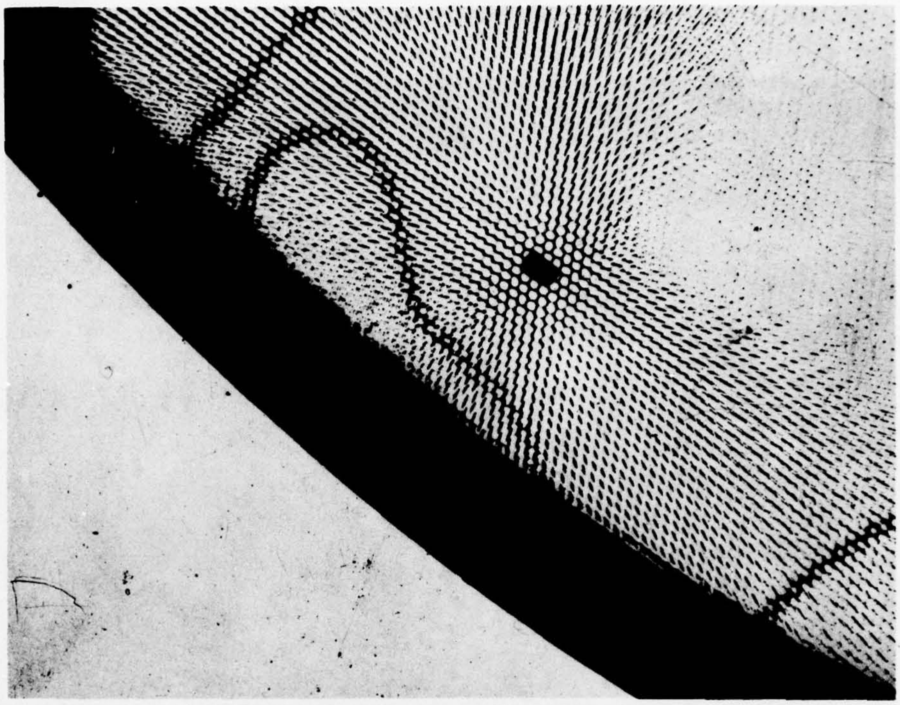
Fig 5a-c Wing tip 8 – top



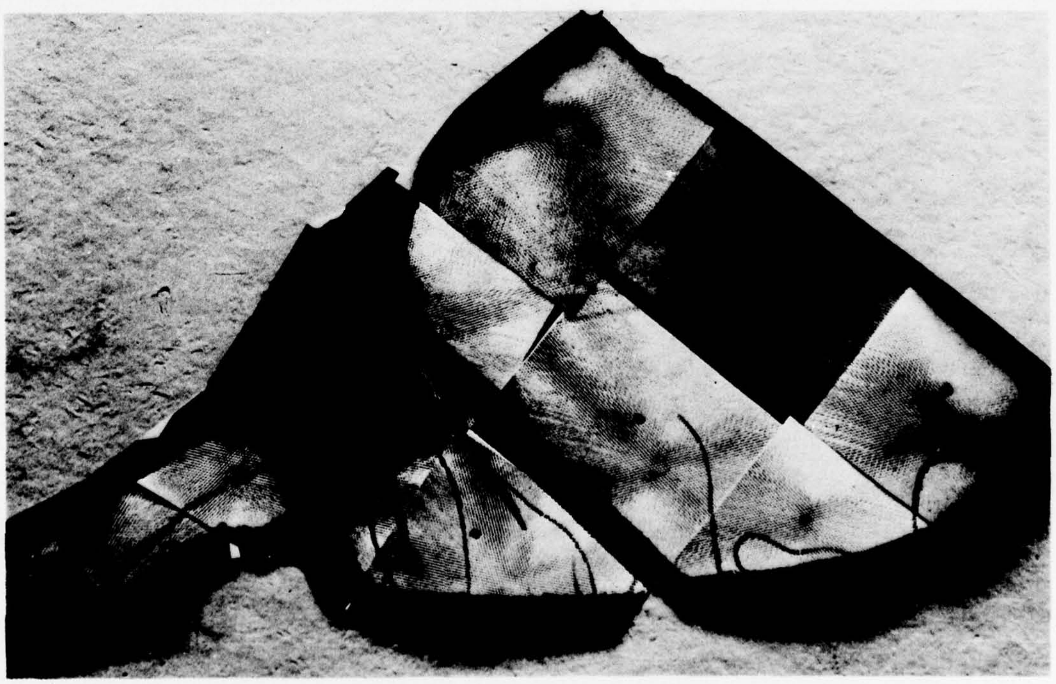
a Level

b Tilted 12°

Fig 6a&b Check of line anomaly in two mounting positions

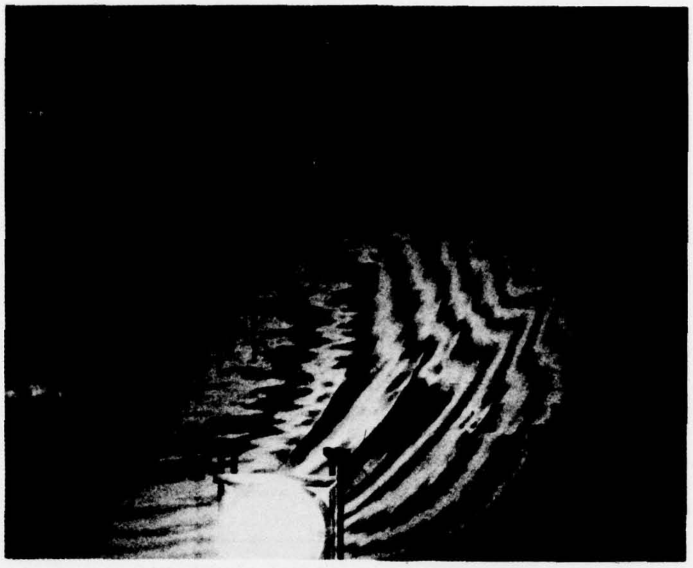


a Radiograph of area near '12'



b Mosaic of radiographs of whole wing tip

Fig 7a&b



a Area 5 – laminae prominent after 4 hours

b Area 6 – irregular fringes after 8 hours

Fig 8a&b Wing tip 8 – bottom

Fig 9a&b

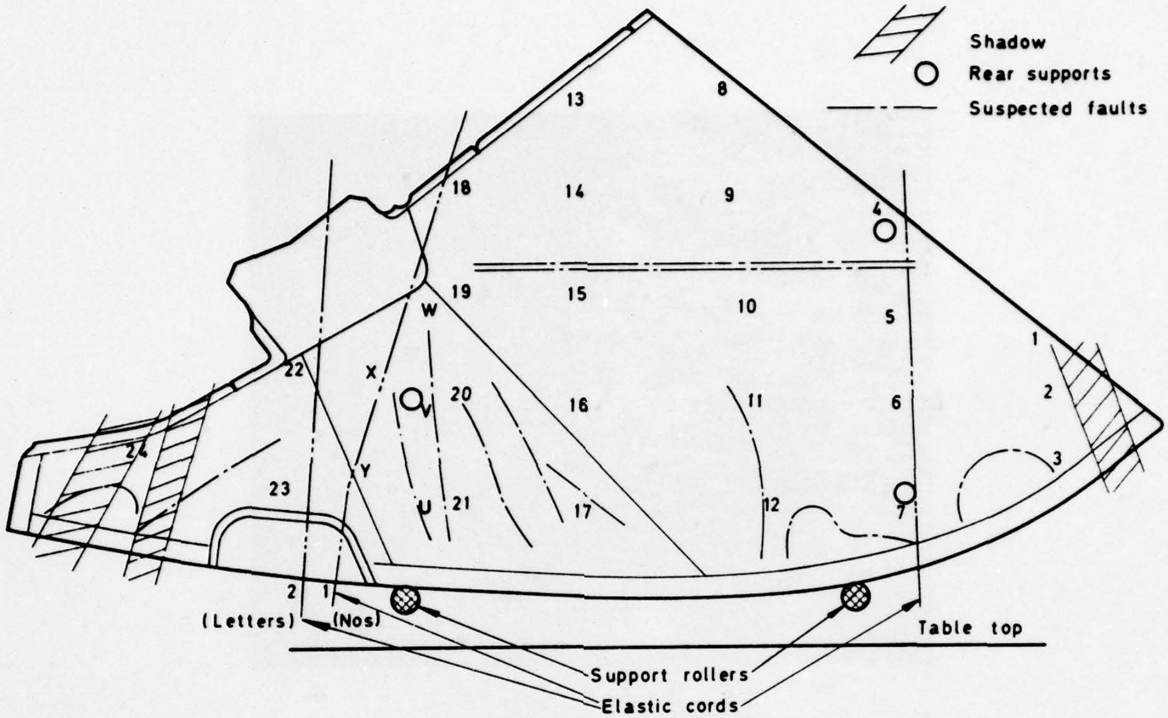


Fig 9a Wing tip 8 – top surface

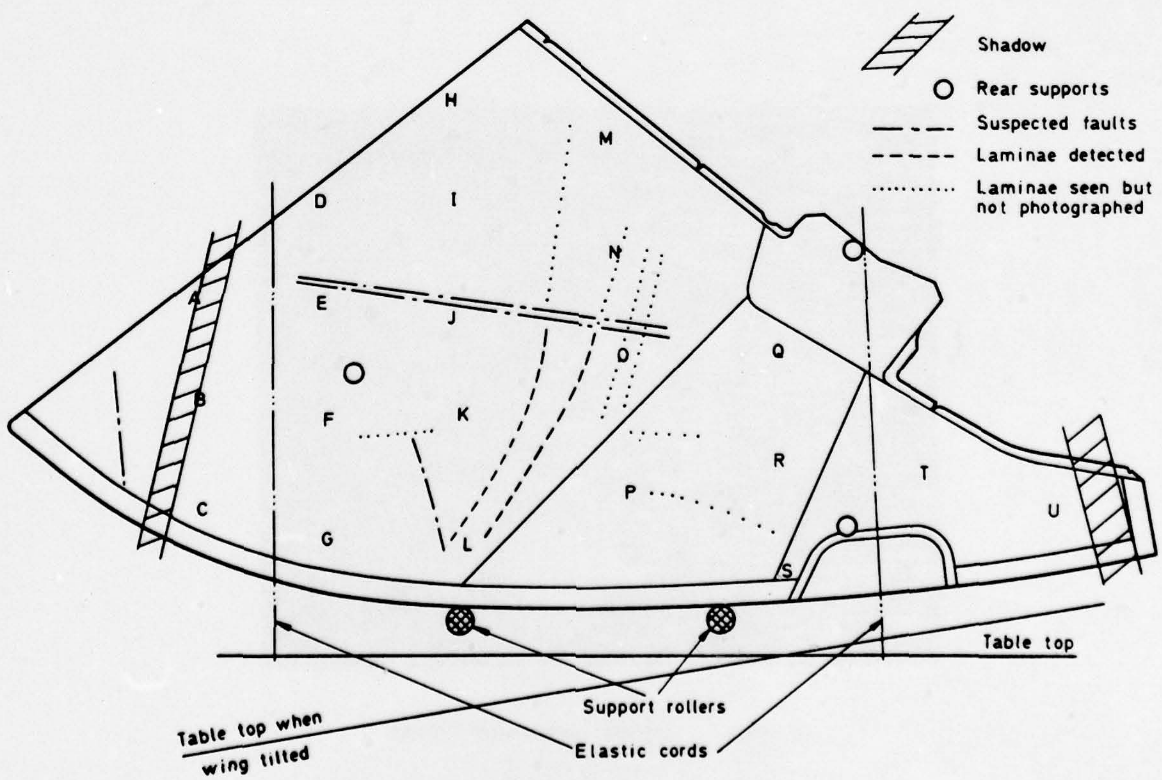


Fig 9b Wing tip 8 – bottom surface

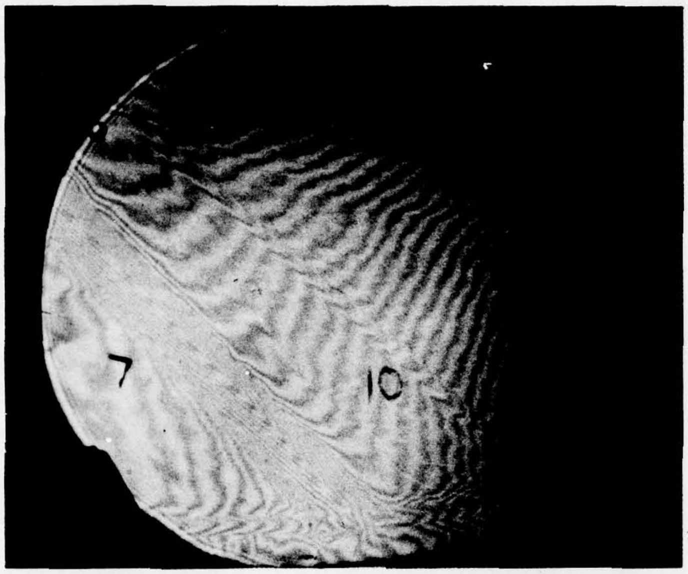


Fig 10 Anomaly corresponding to cement on rear surface

Fig 11 Suspected debond

Fig 12a

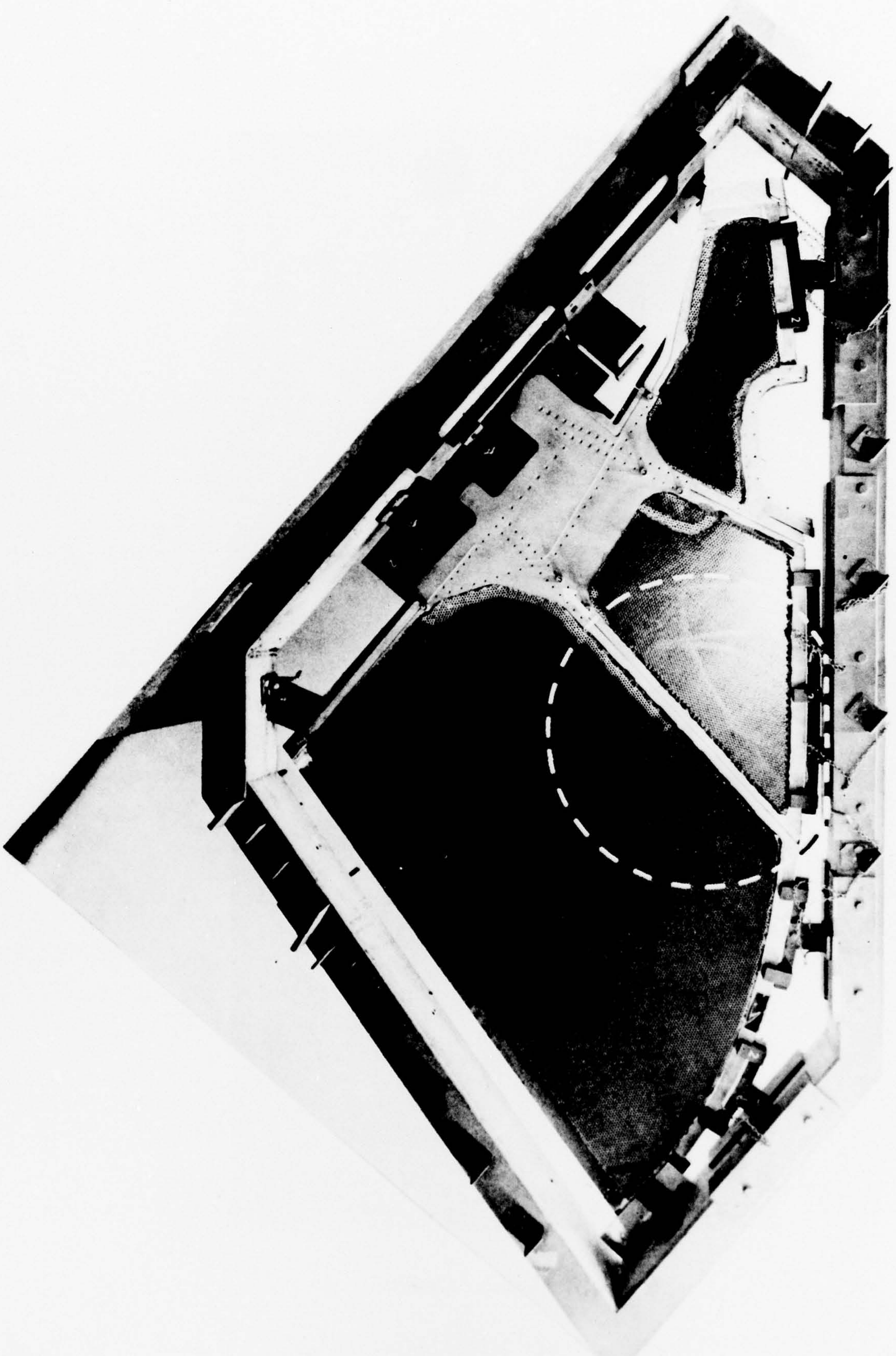


Fig 12a Wing tip 12 before skin attached

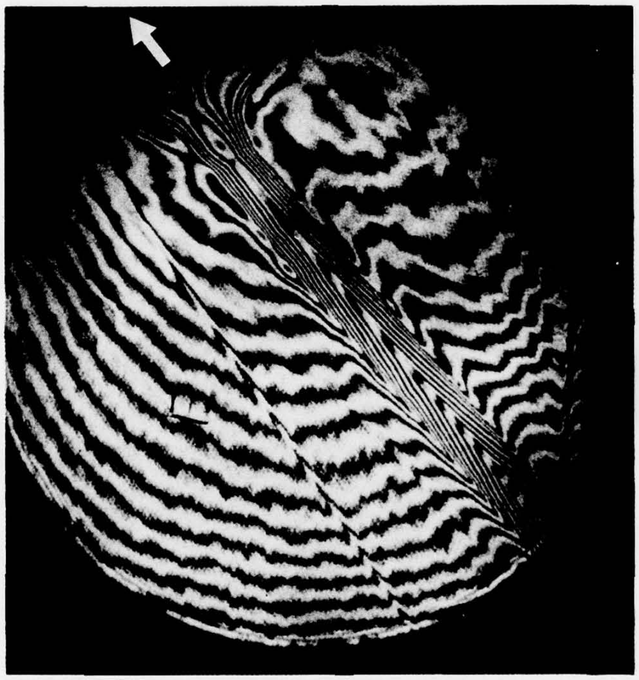


Fig 12b Patterns in area indicated by dashed circle

Fig 13 Whole surface illuminated

Fig 14 Double pulse photograph

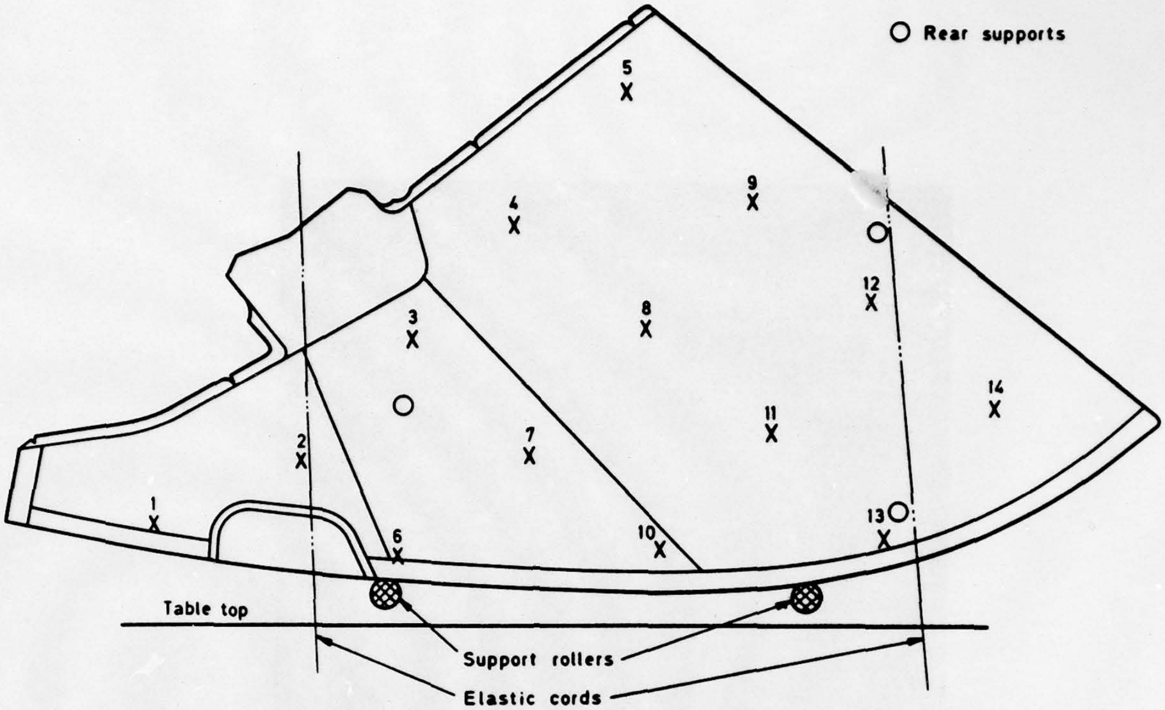


Fig A1a Wing tip 4 — top surface

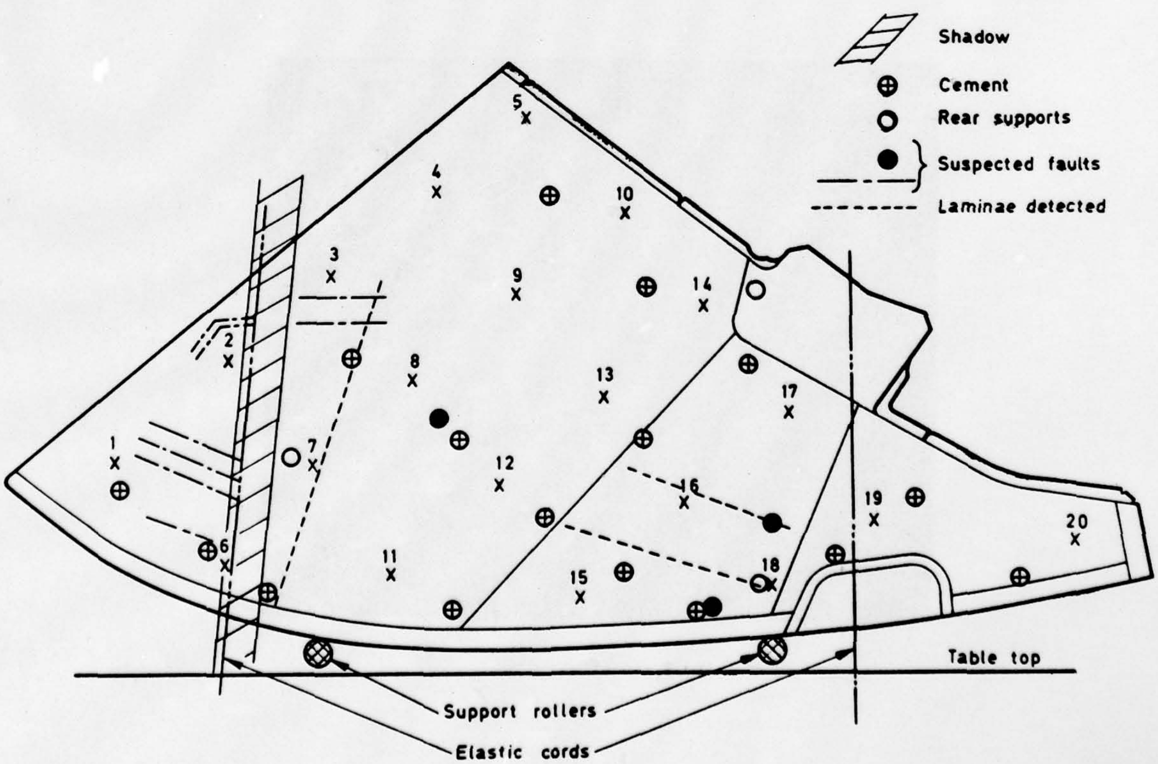
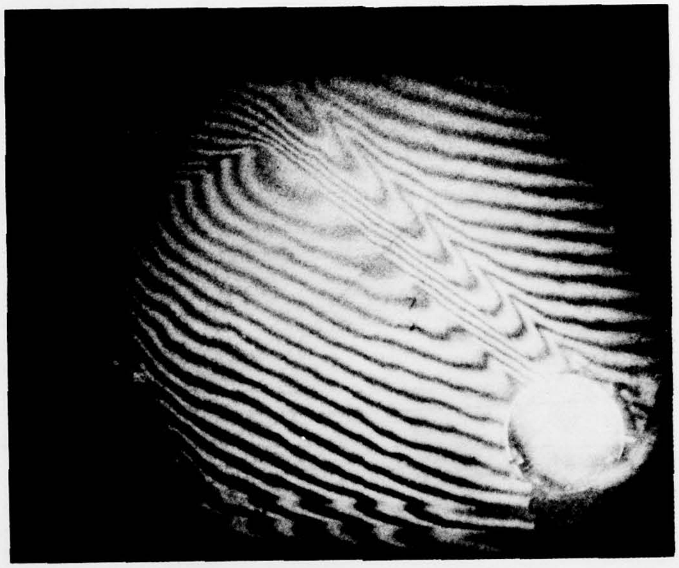


Fig A1b Wing tip 4 — bottom surface



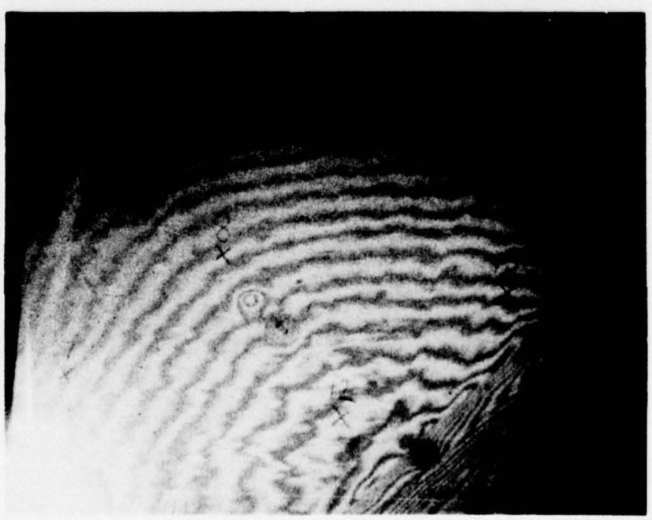
a Direct photograph of live fringes

b From TV monitor

Fig A2a&b Wing tip 4 — top

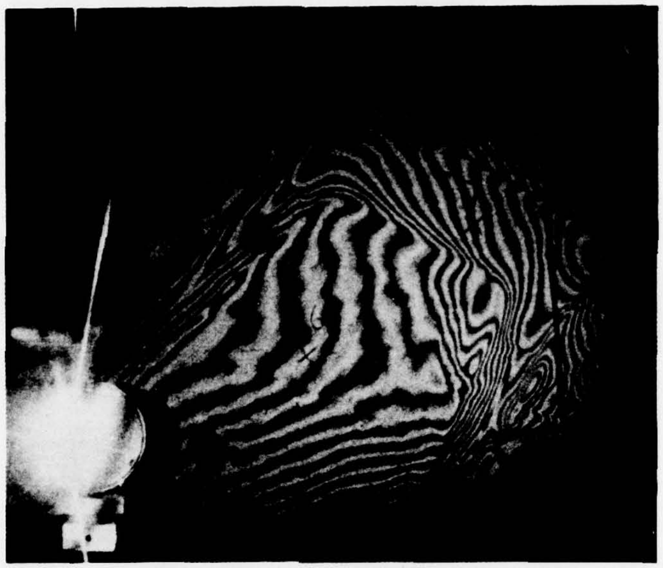
a

b



c

Fig A3a-c Wing tip 4 — bottom



d

e

Fig A3d&e

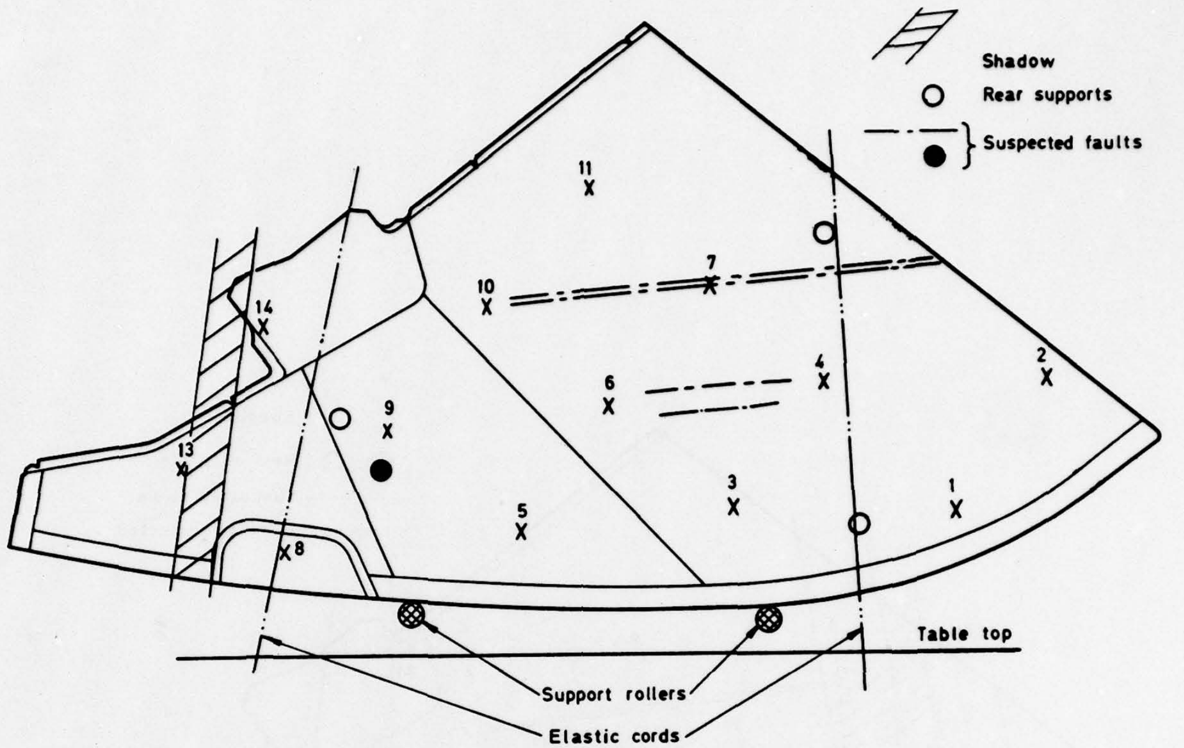


Fig A4a Wing tip 6 – top surface (first run)

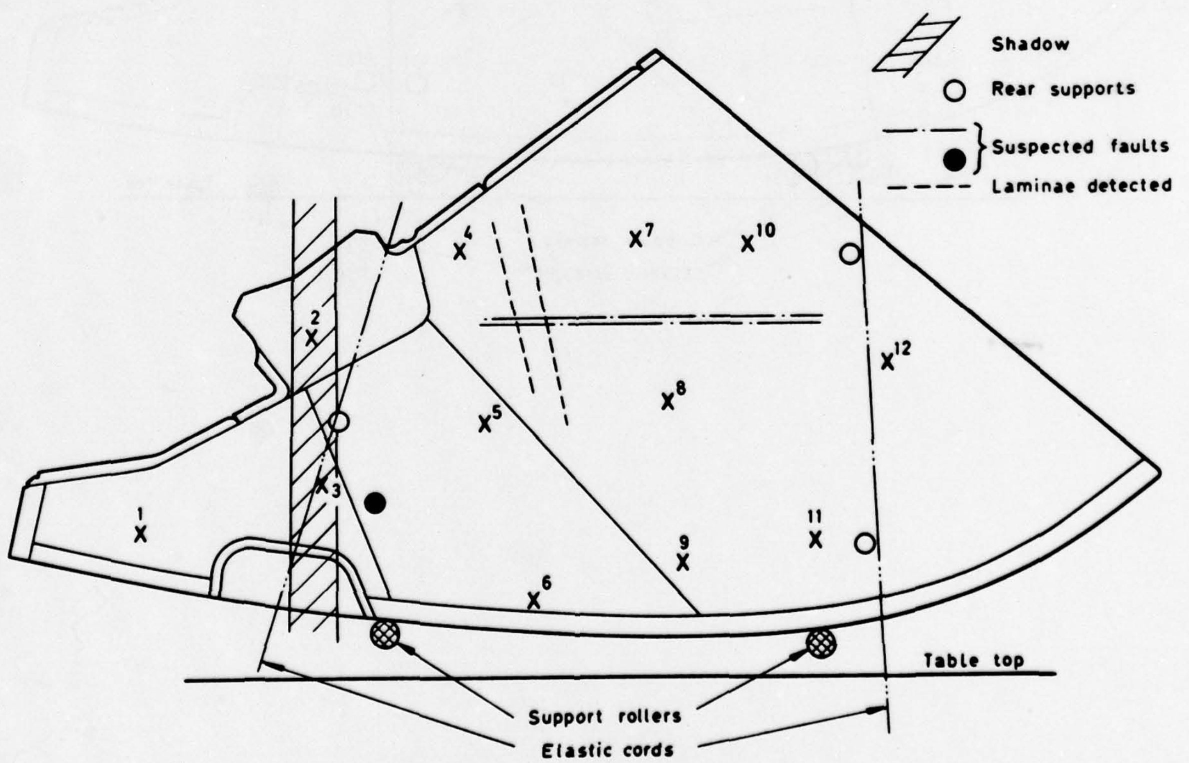


Fig A4b Wing tip 6 – top surface (second run)

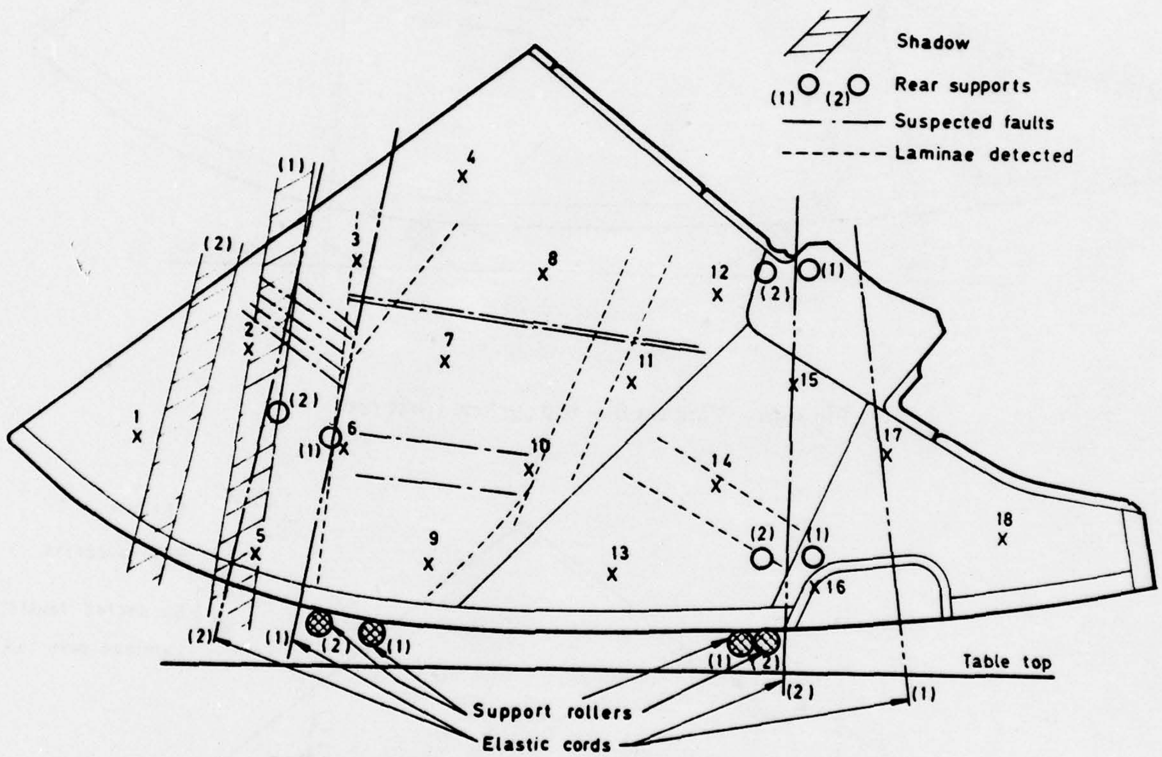
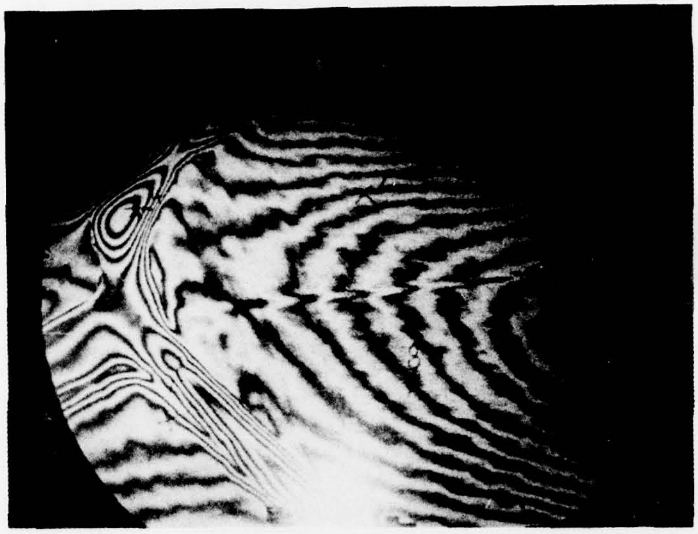
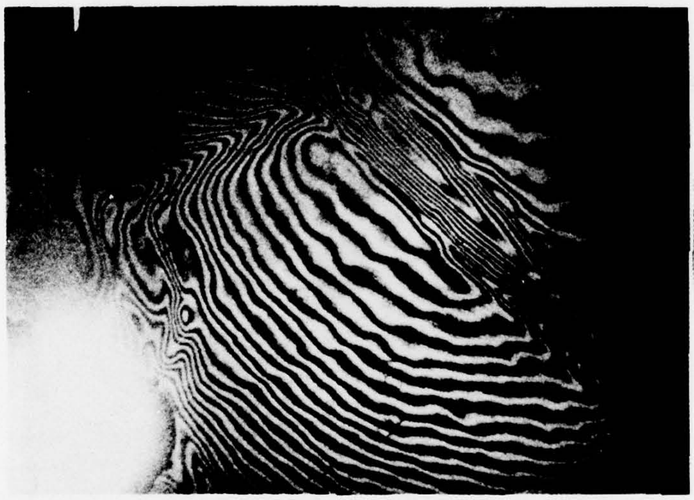


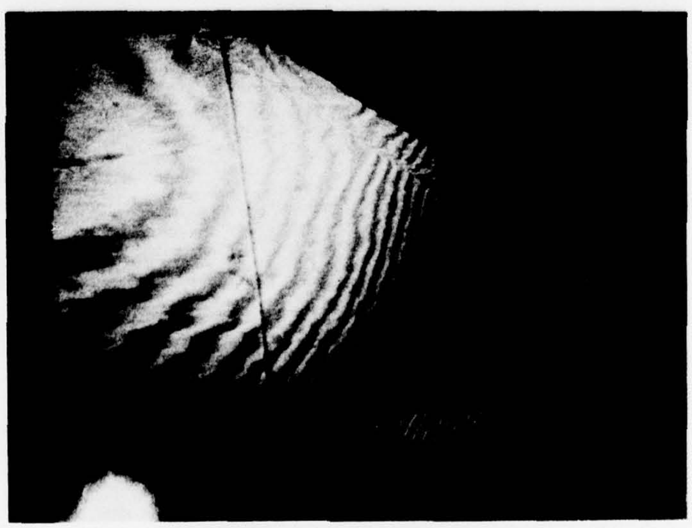
Fig A4c Wing tip 6 — bottom surface



a



b



c

Fig A5a-c Wing tip 6 — top

d

e

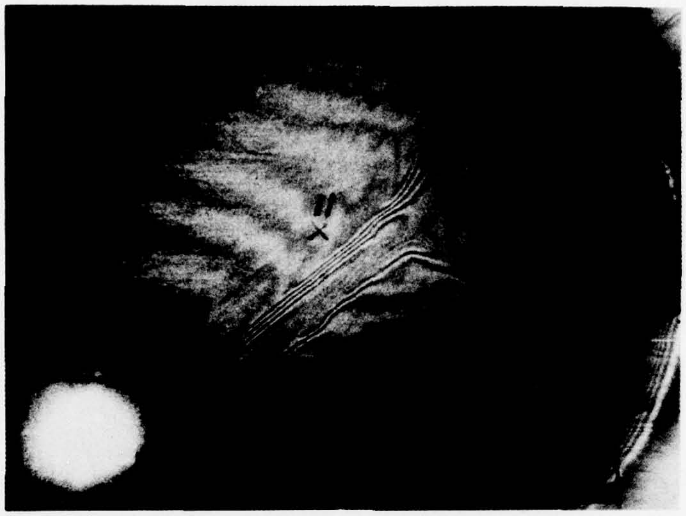
Fig A5d&e

a

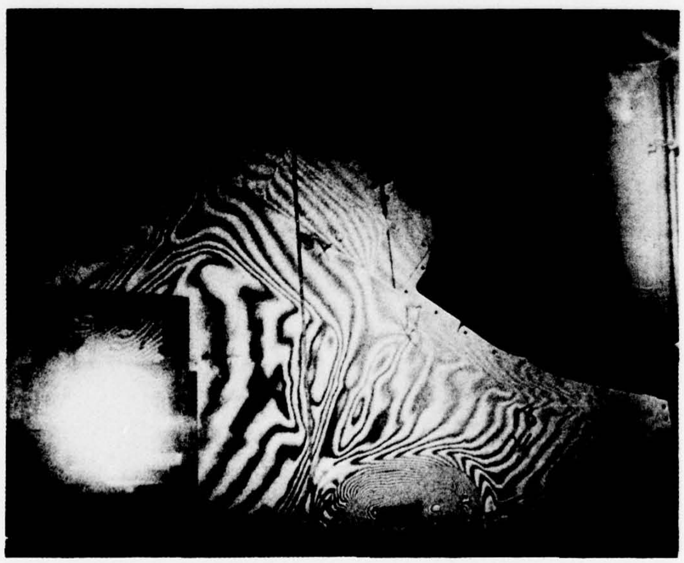
b

c

Fig A6a-c Wing tip 6 — bottom



d



e

Fig A6d&e

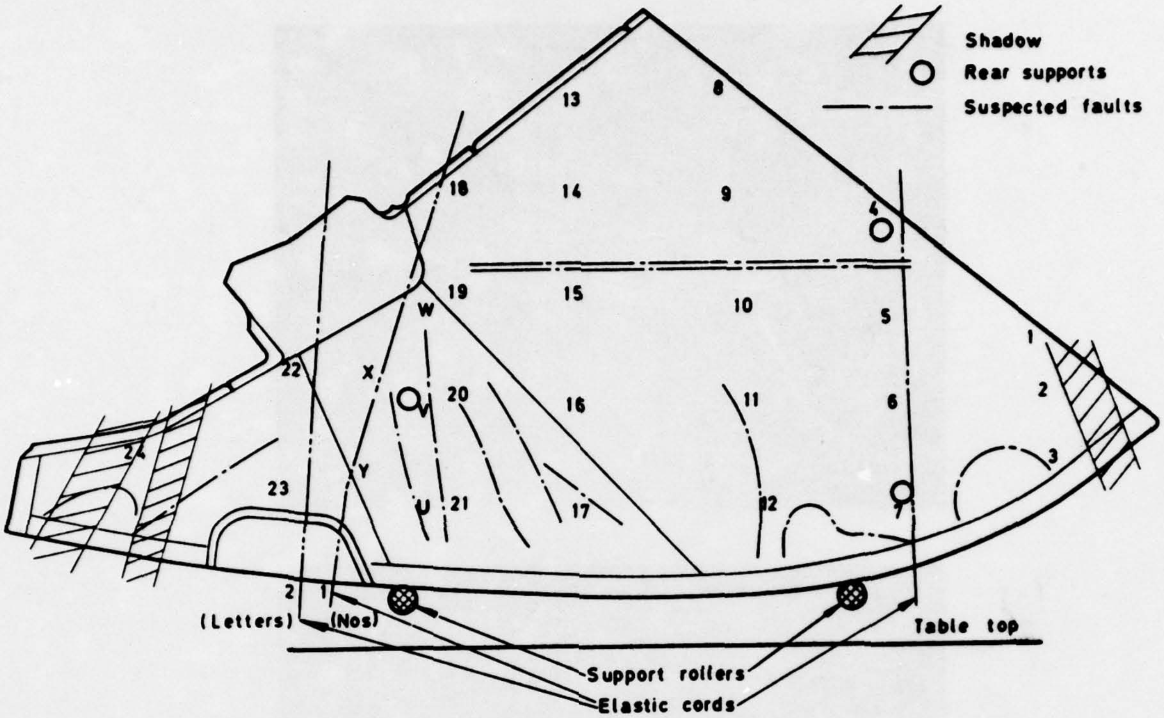


Fig A7a Wing tip 8 — top surface

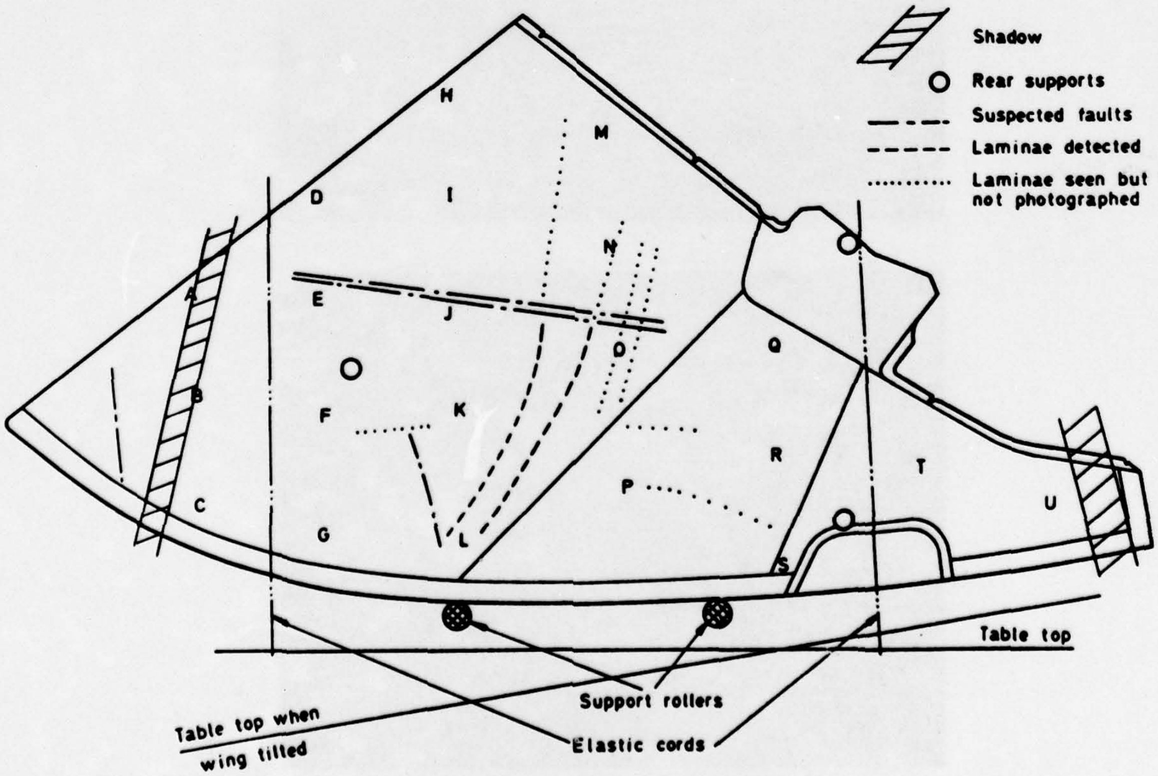


Fig A7b Wing tip 8 — bottom surface

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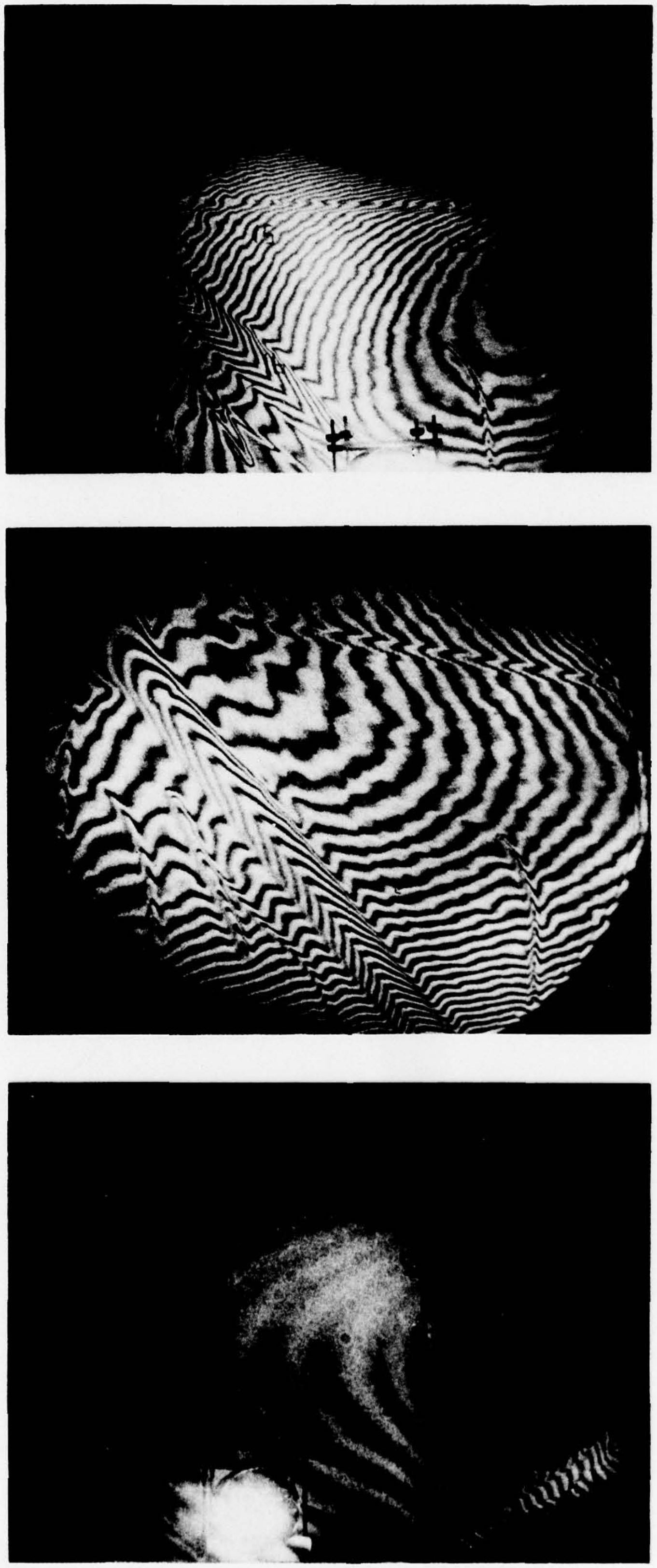


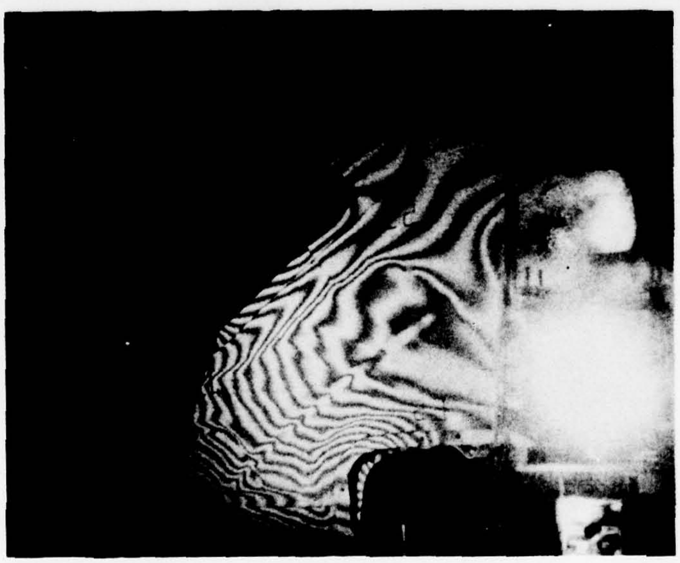
a

b

c

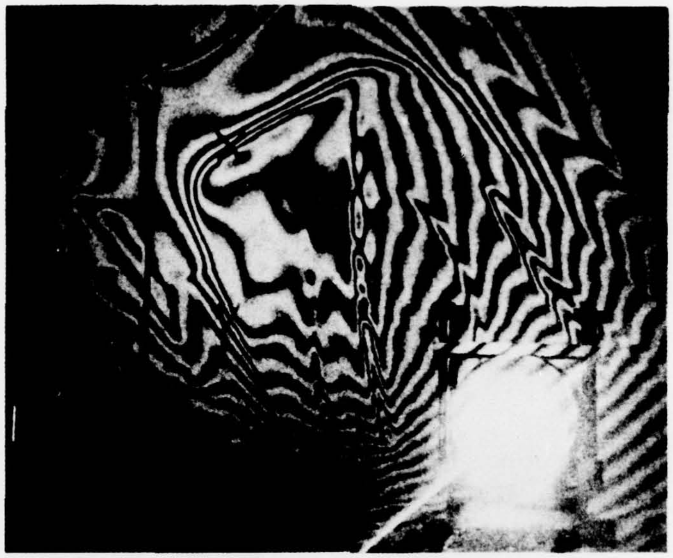
Fig A8a-c Wing tip 8 — top

d

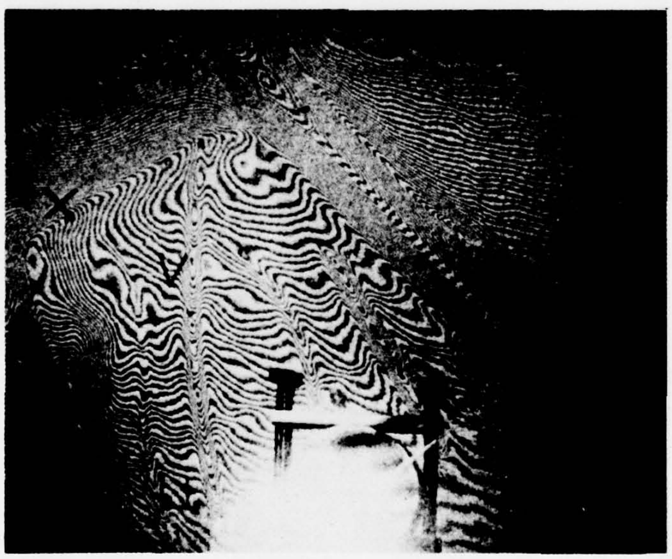


e

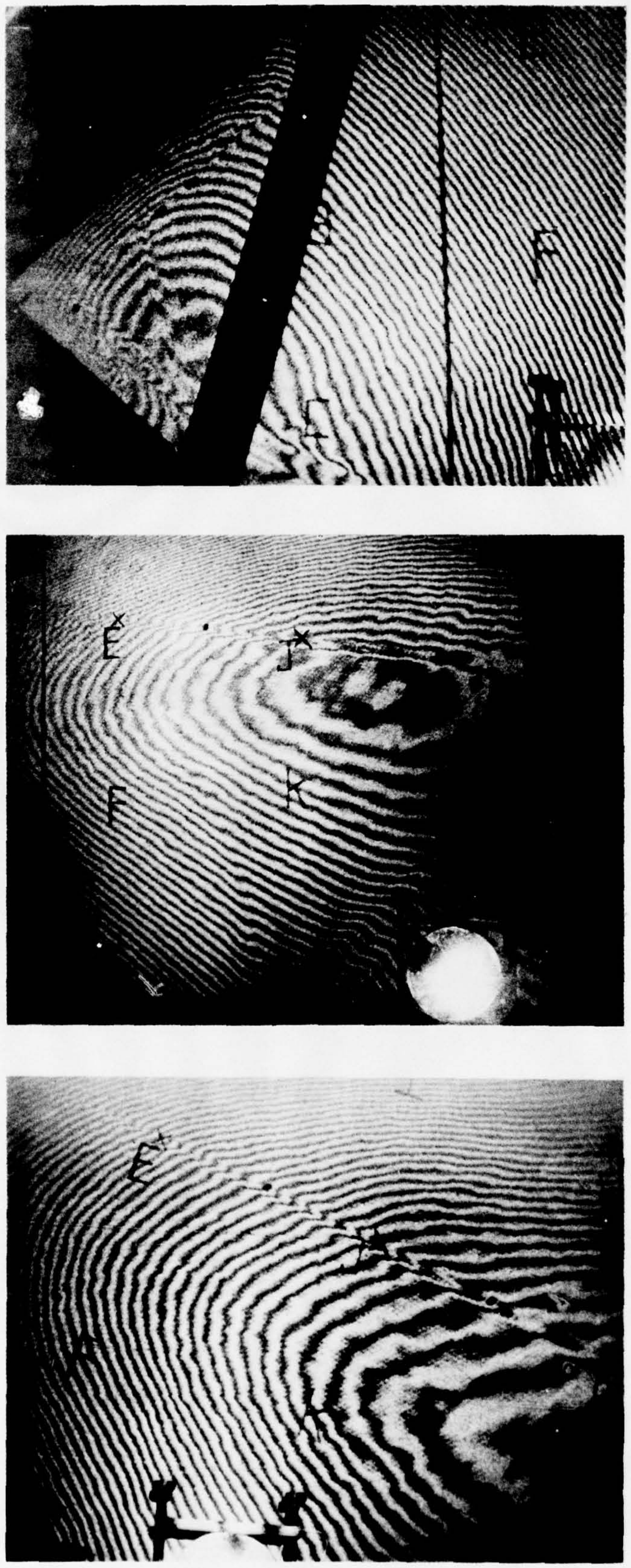
Fig A8d&e



f Detection of remaining fault (see main report)



g After 4 hours – compare Fig 8b



a

b

c

Fig A9a-c Wing tip 8 – bottom

d

e

Fig A9d & e

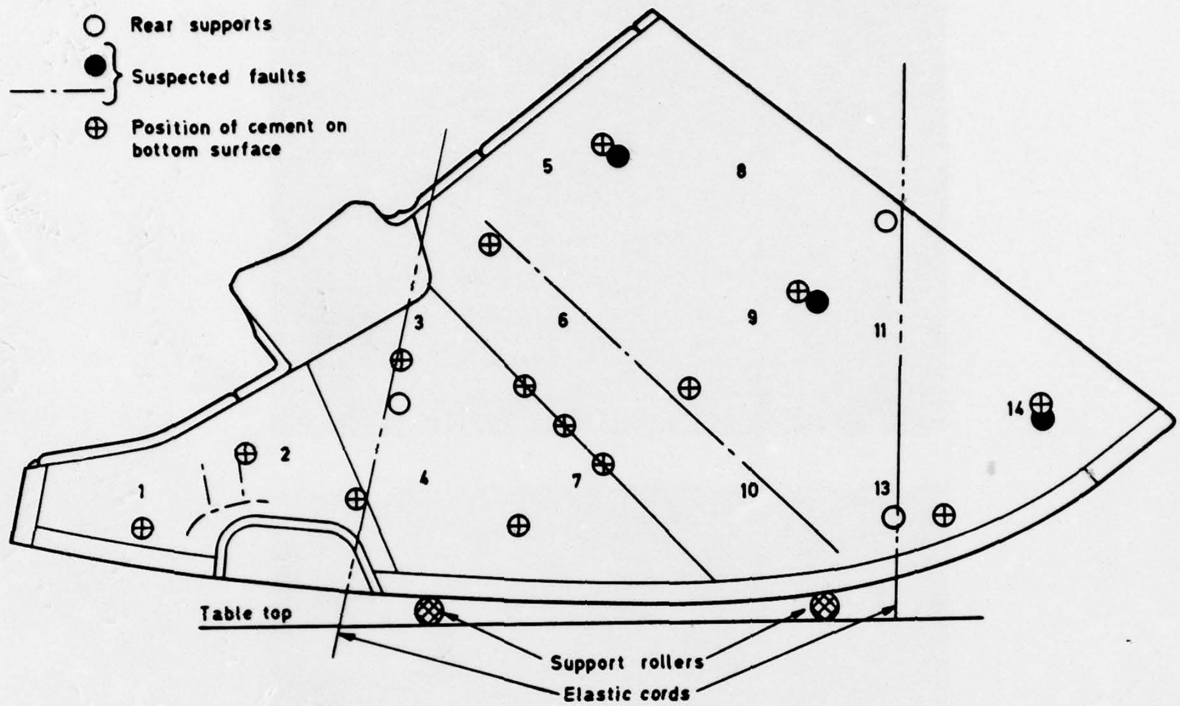


Fig A10a Wing tip 10 – top surface

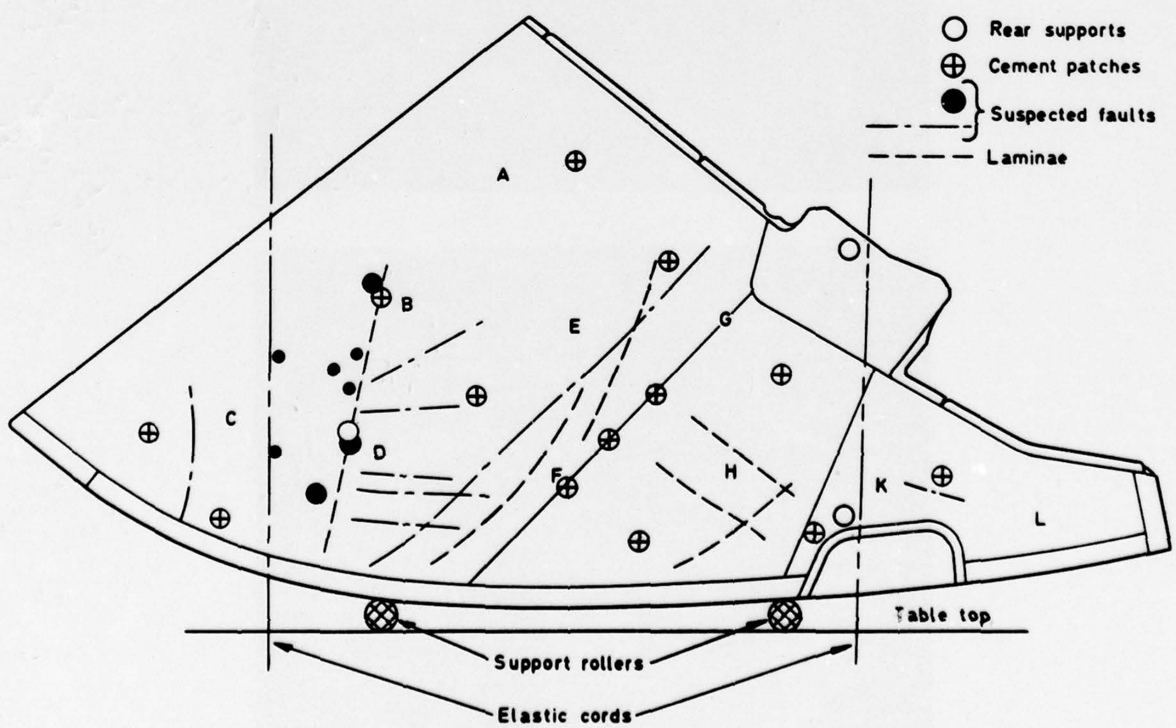
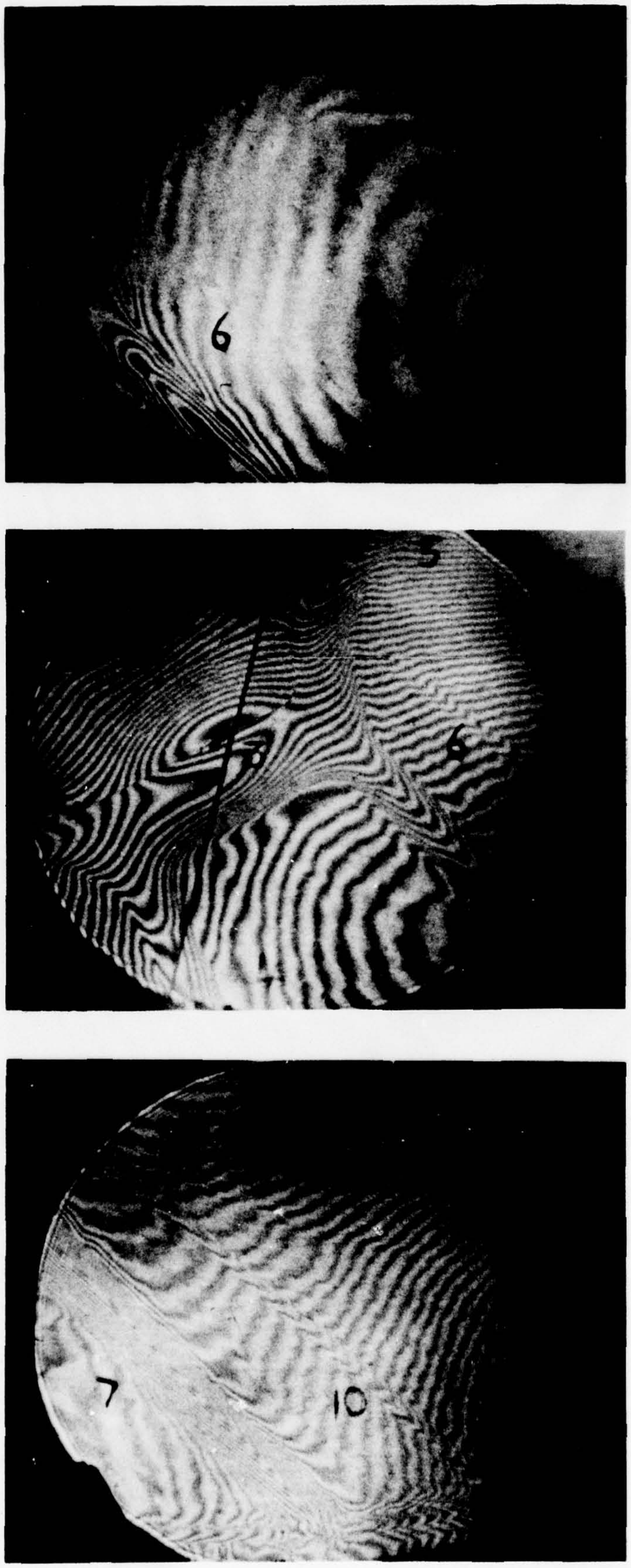


Fig A10b Wing tip 10 – bottom surface

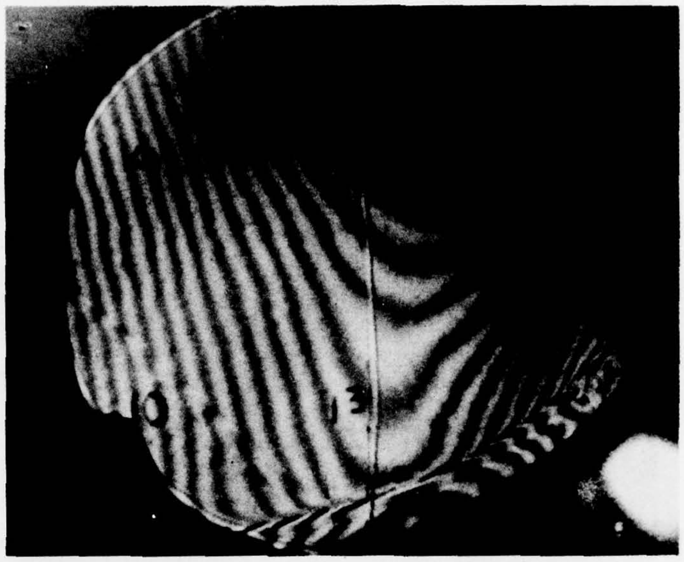


a

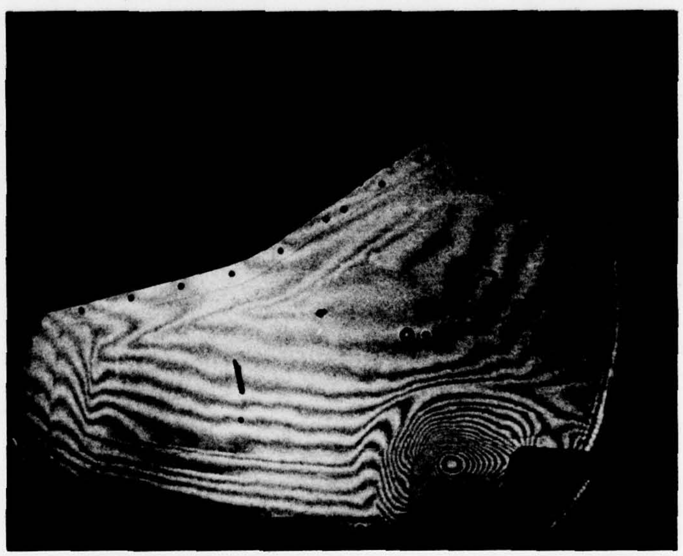
b

c

Fig A11a-c Wing tip 10 — top

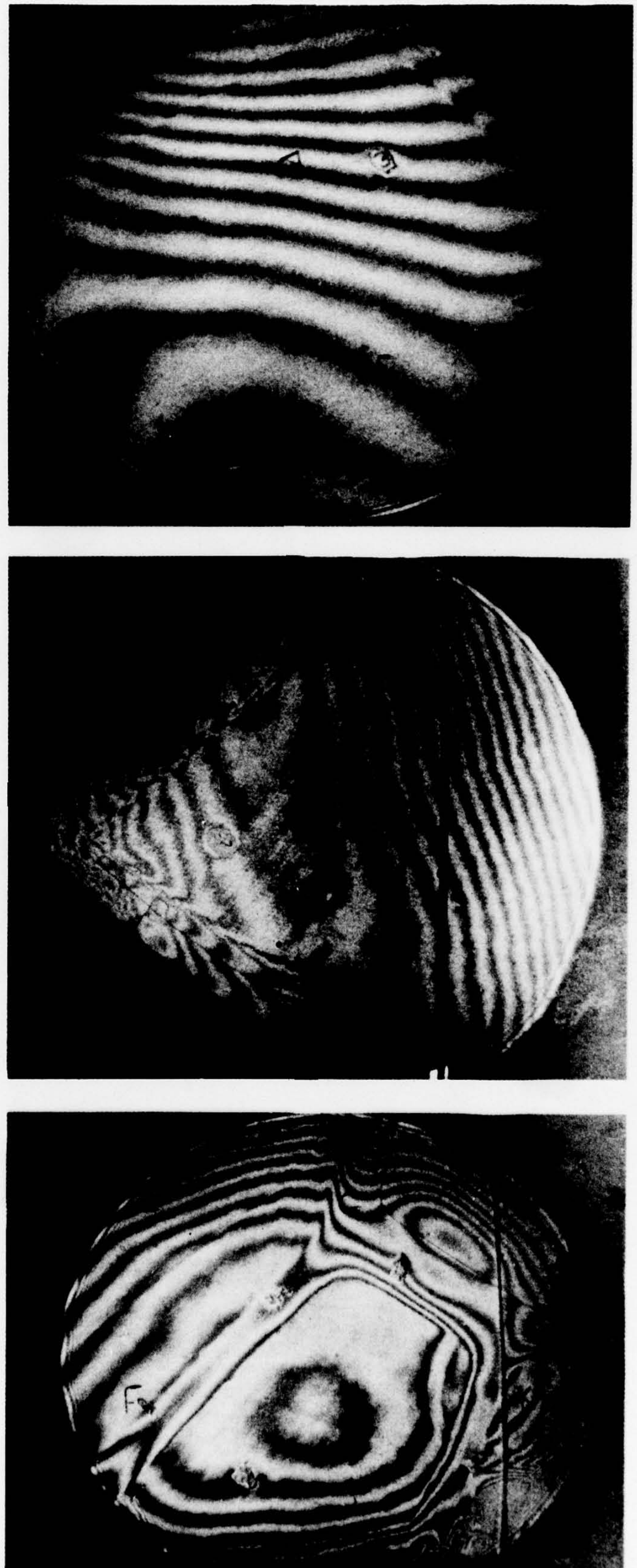


d



e

Fig A11d&e

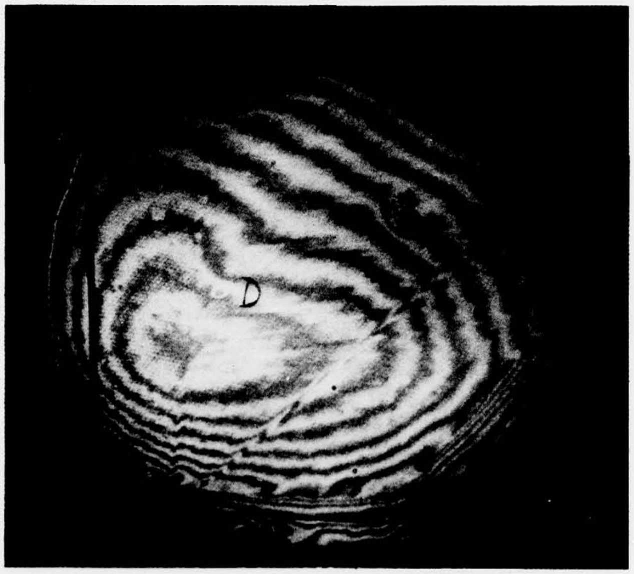


a

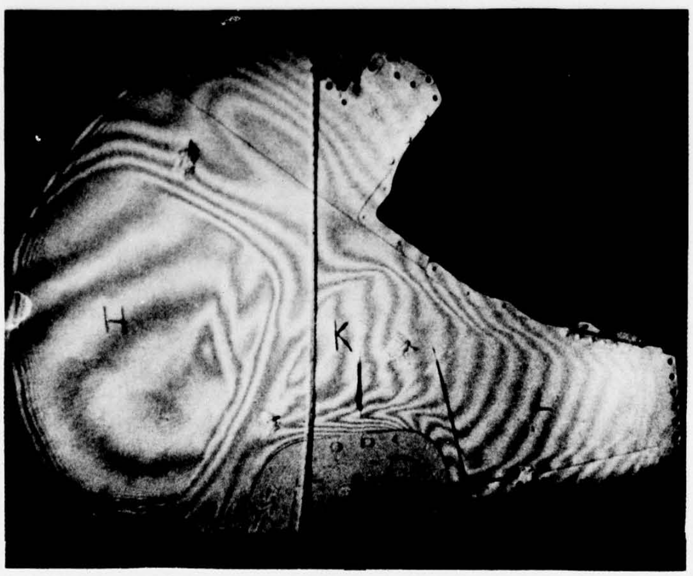
b

c

Fig A12a-c Wing tip 10 — bottom



d



e

Fig A12d&e

Fig A13a&b

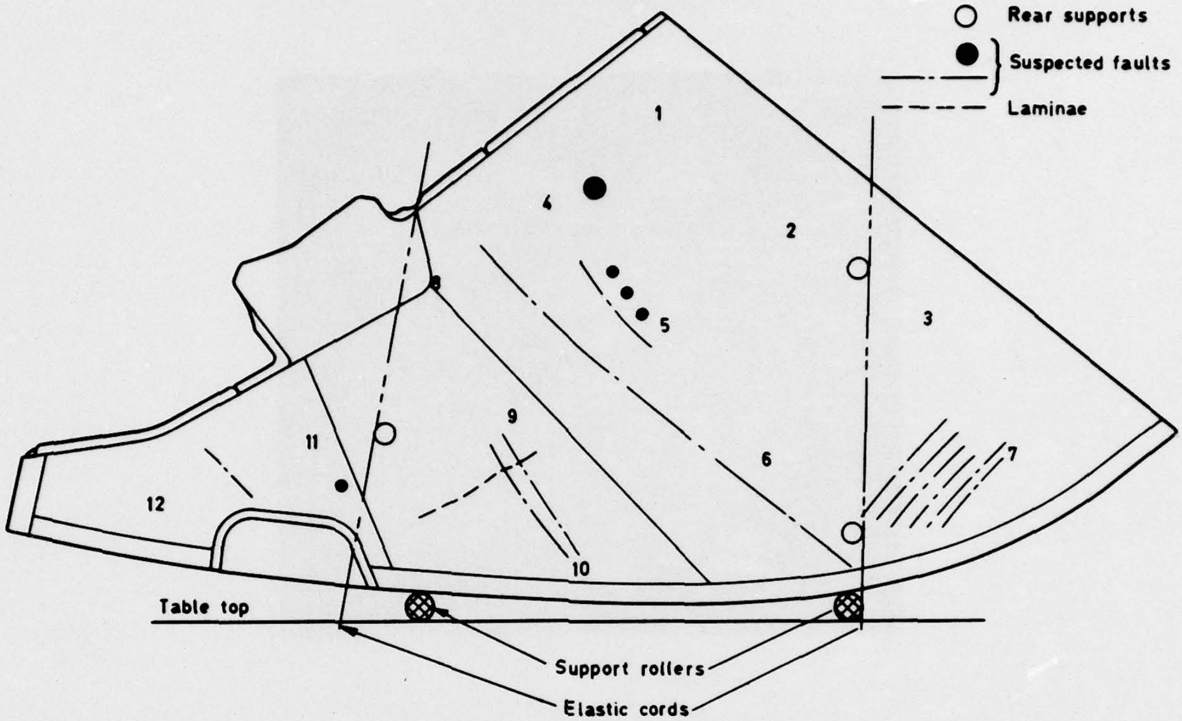


Fig A13a Wing tip 12 – top surface

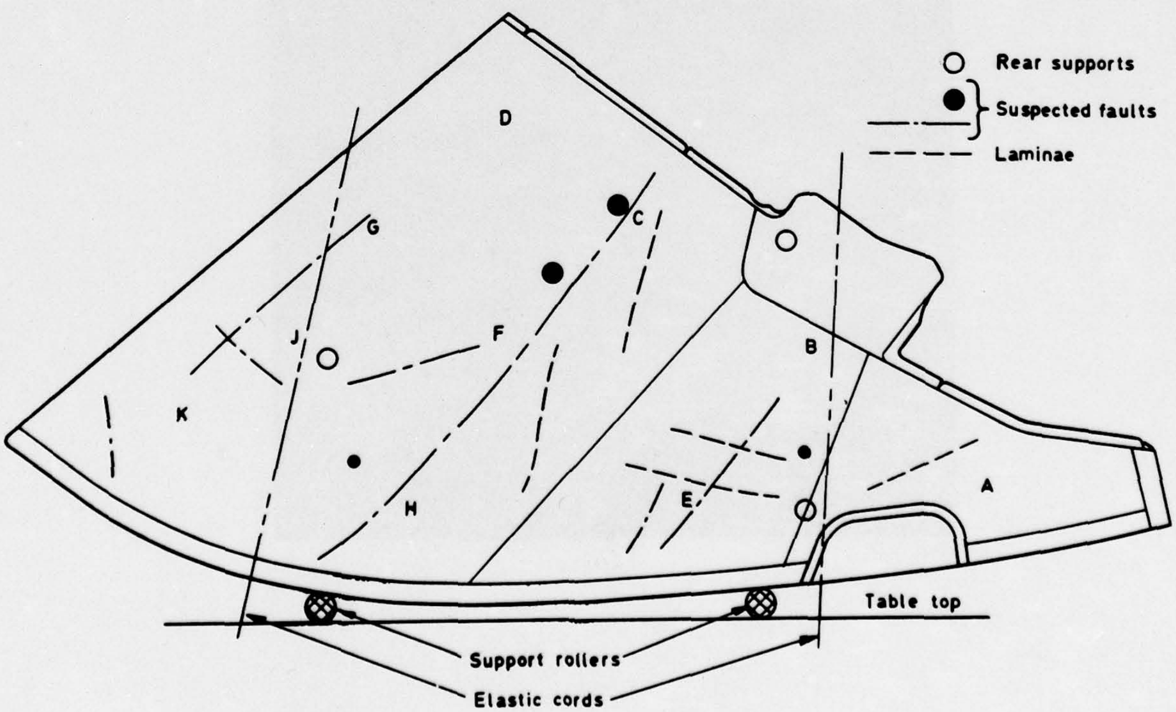


Fig A13b Wing tip 12 – bottom surface

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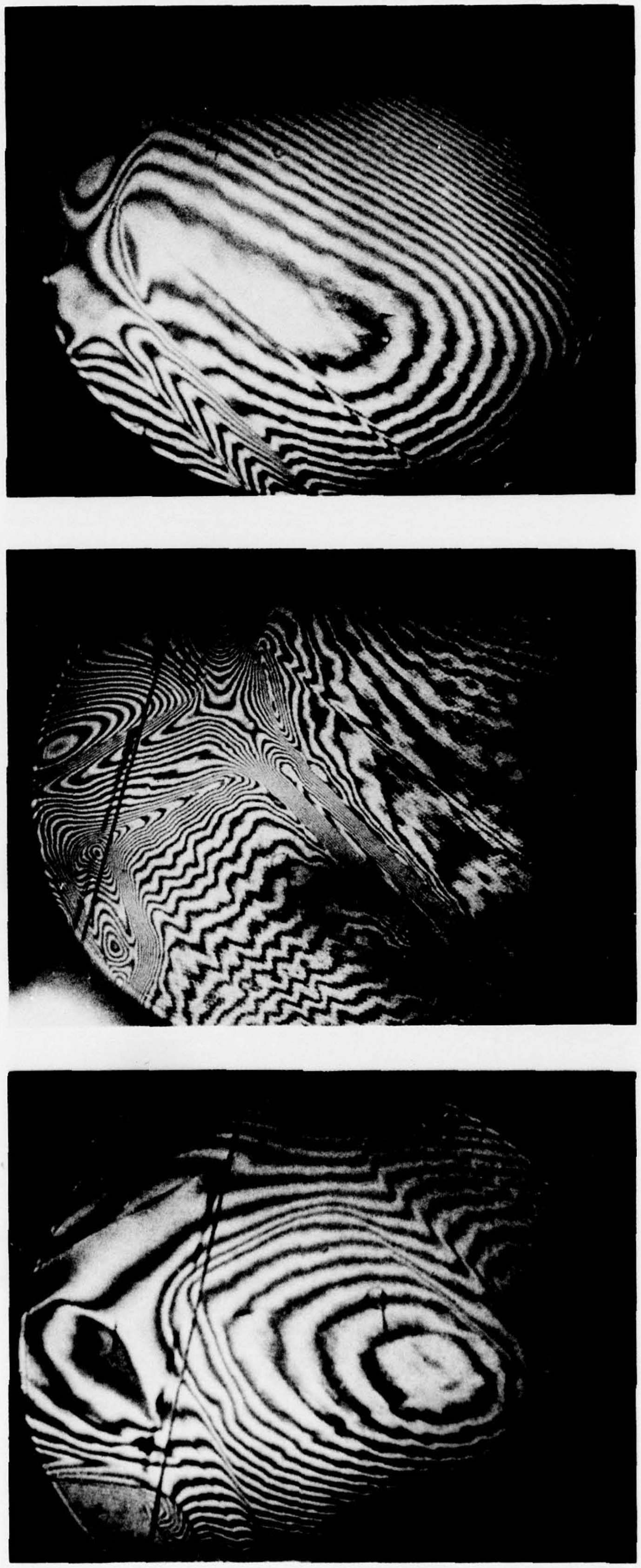
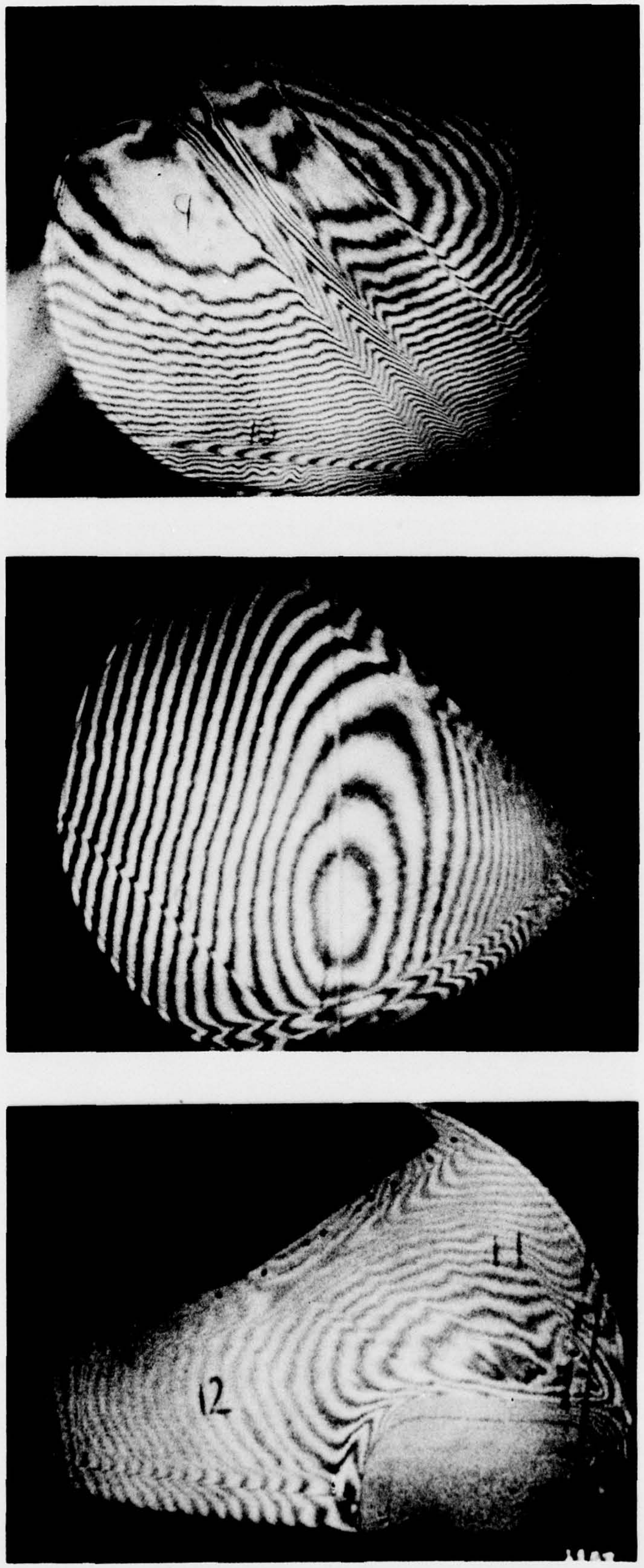


a

b

c

Fig A14a-c Wing tip 12 — top

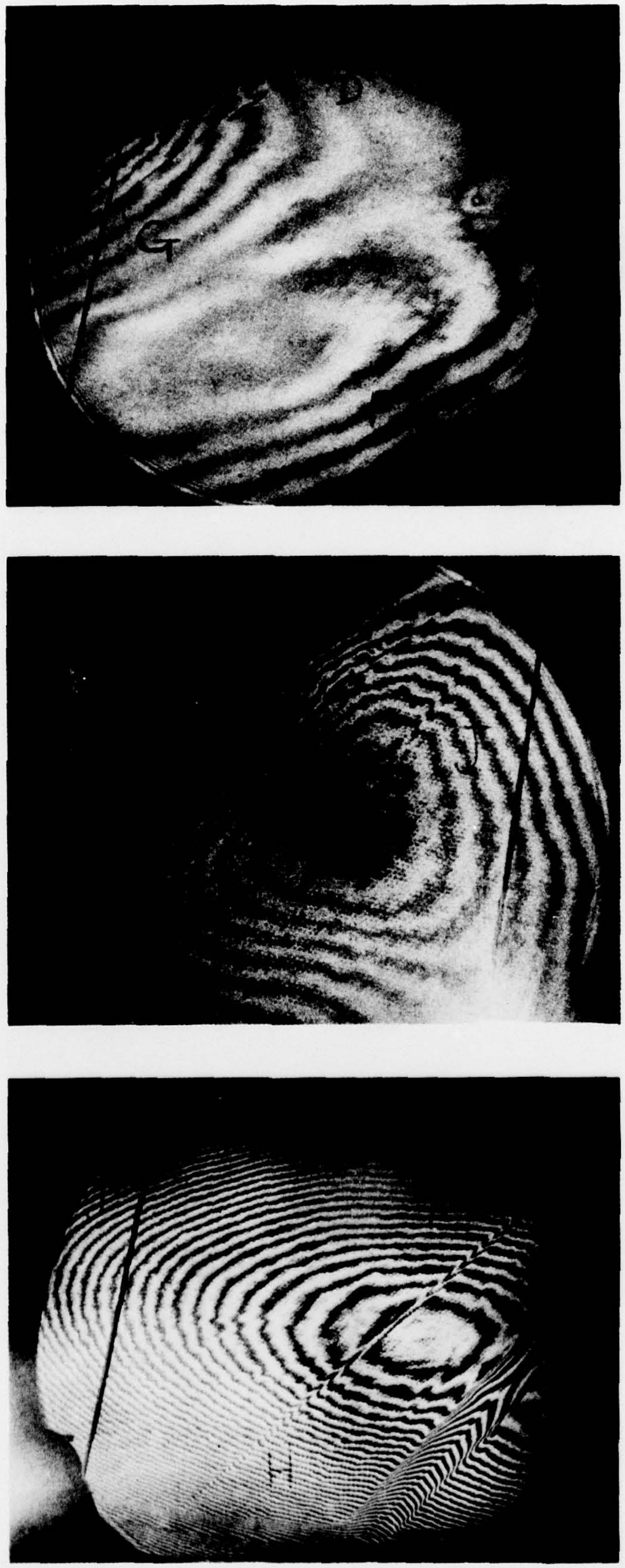


d

e

f

Fig A14d-f

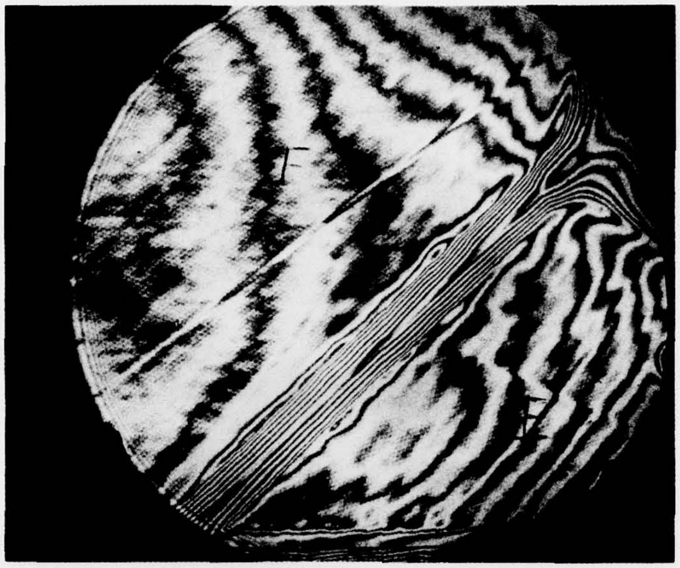


a

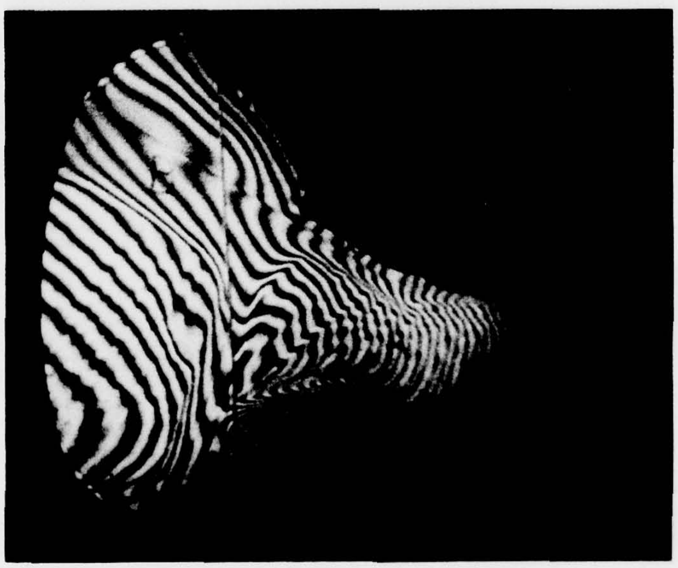
b

c

Fig A15a-c Wing tip 12 — bottom



d



e

Fig A15d & e

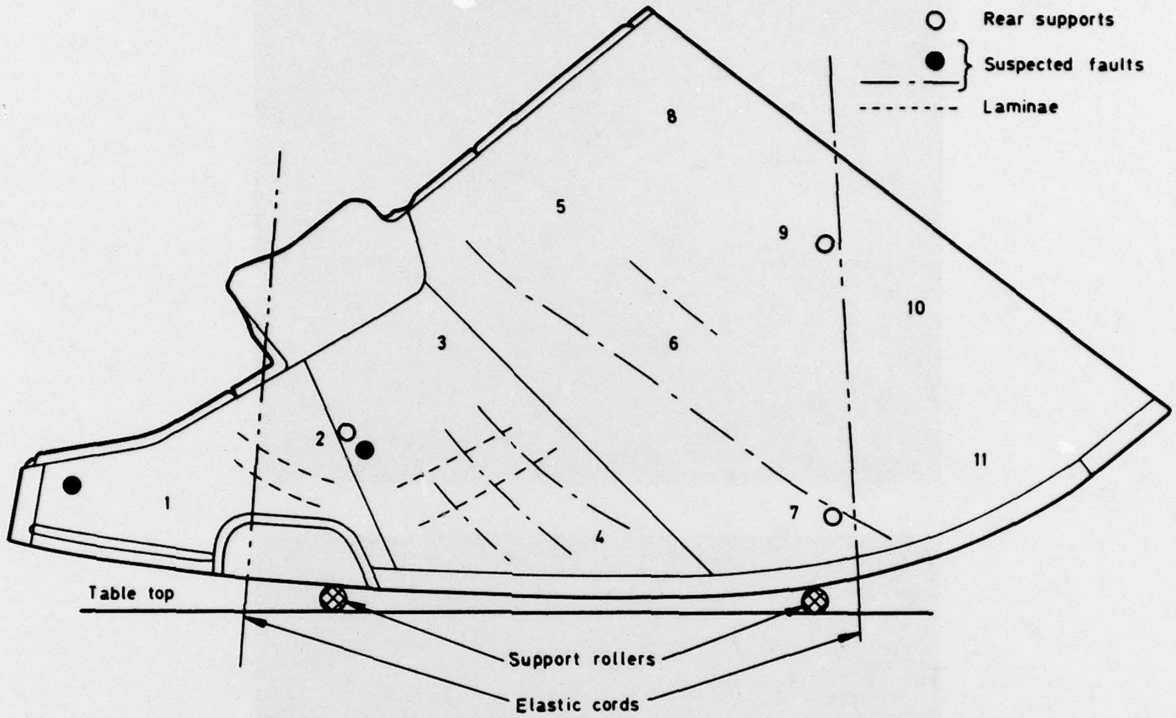


Fig A16a Wing tip 13 – top surface

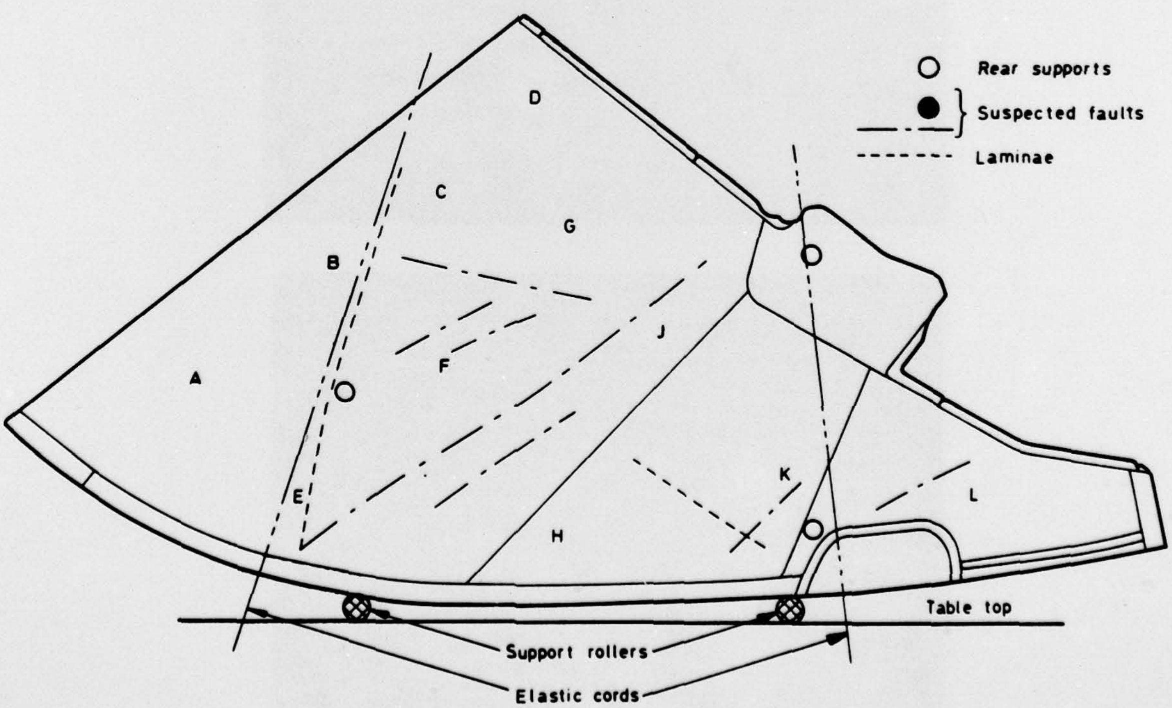
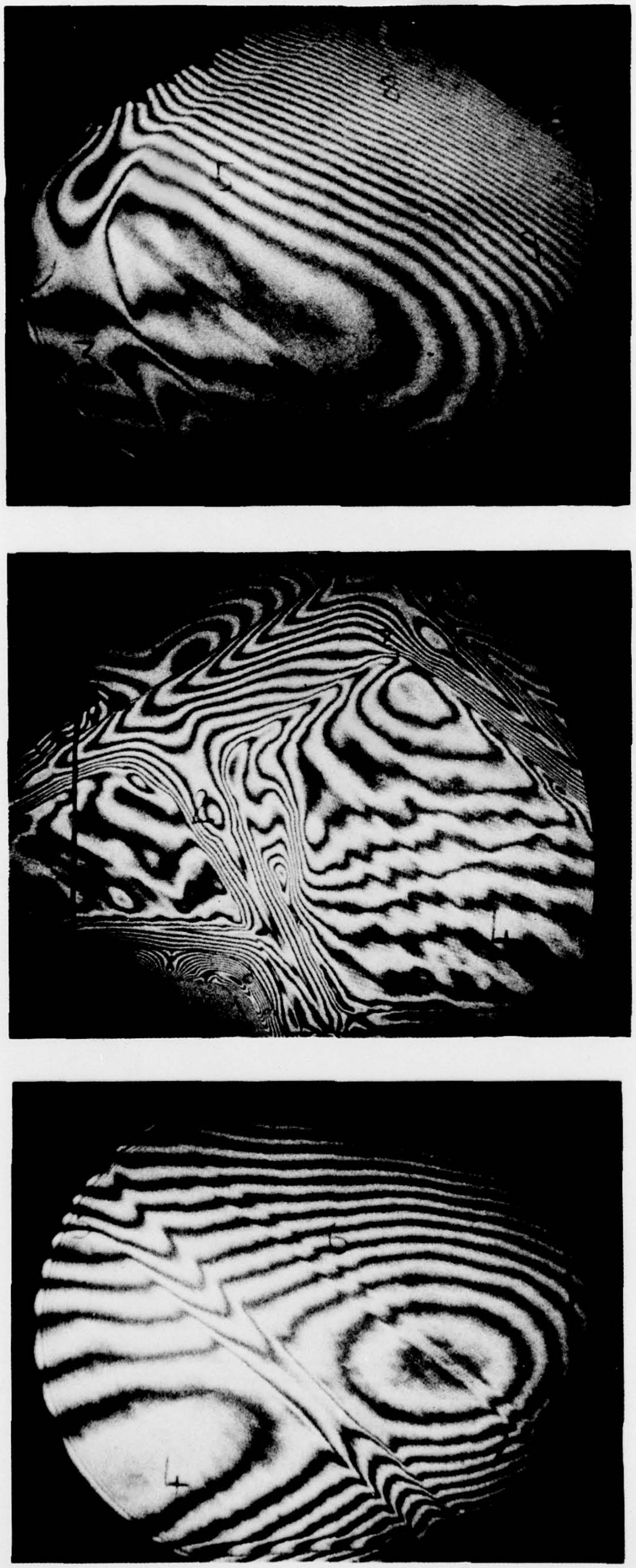


Fig A16b Wing tip 13 – bottom surface

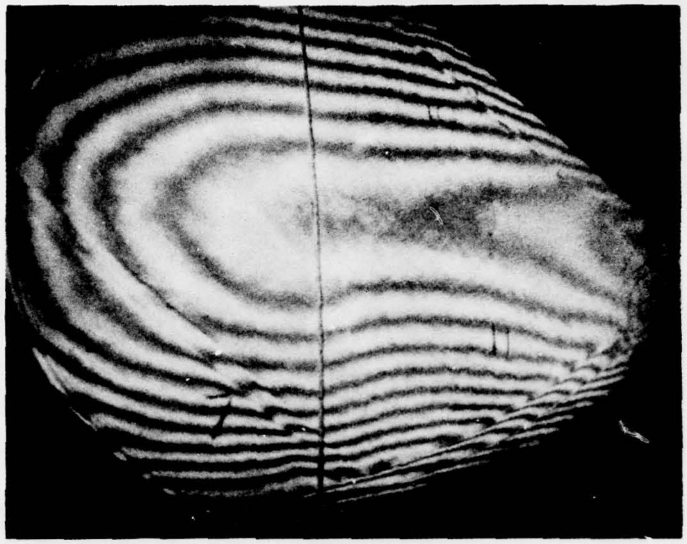


a

b

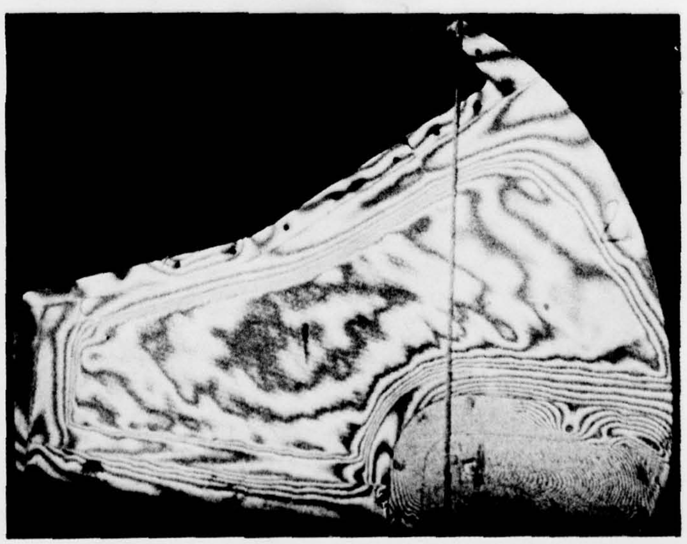
c

Fig A17a-c   Wing tip 13 – top



d

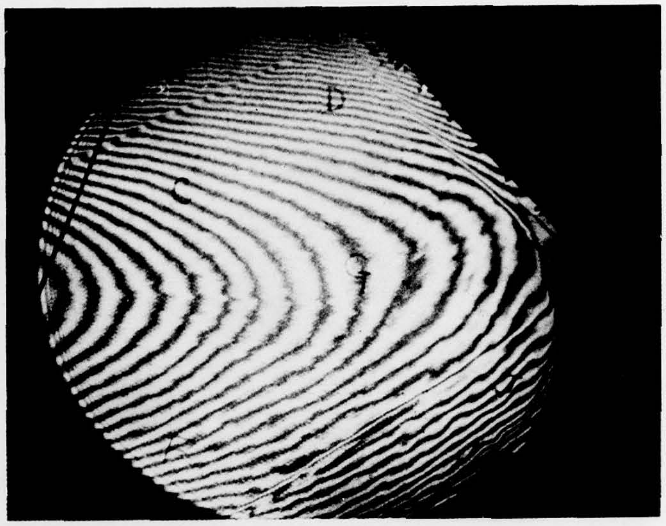
e



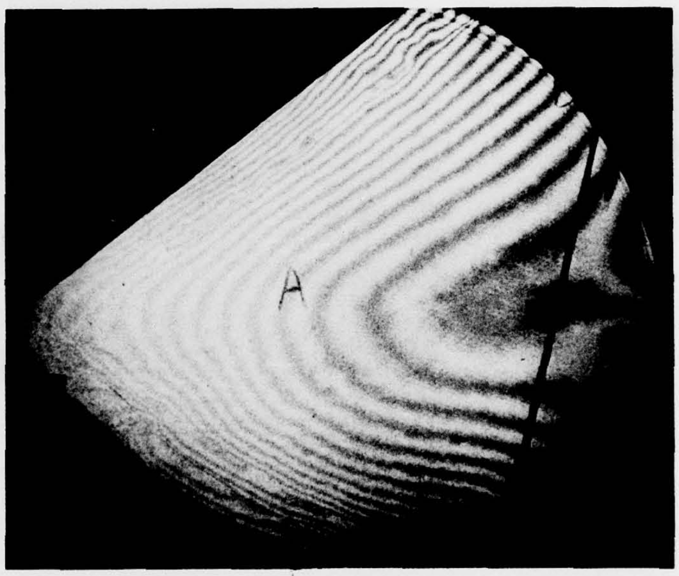
f

Fig A17d-f

Fig A18a-c



a



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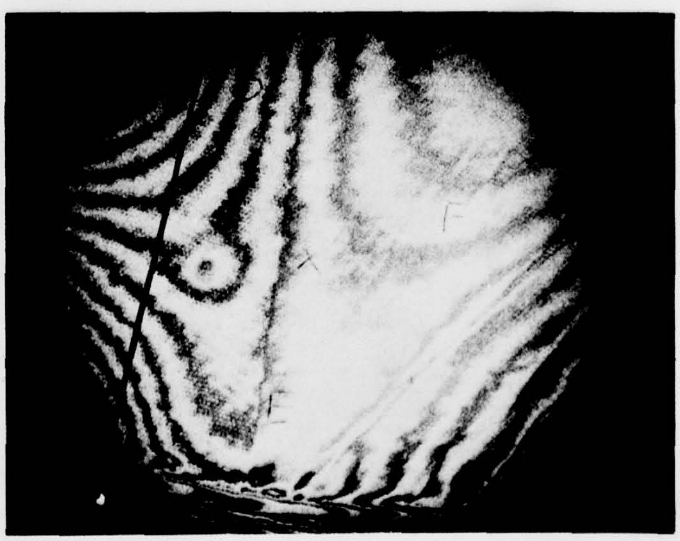
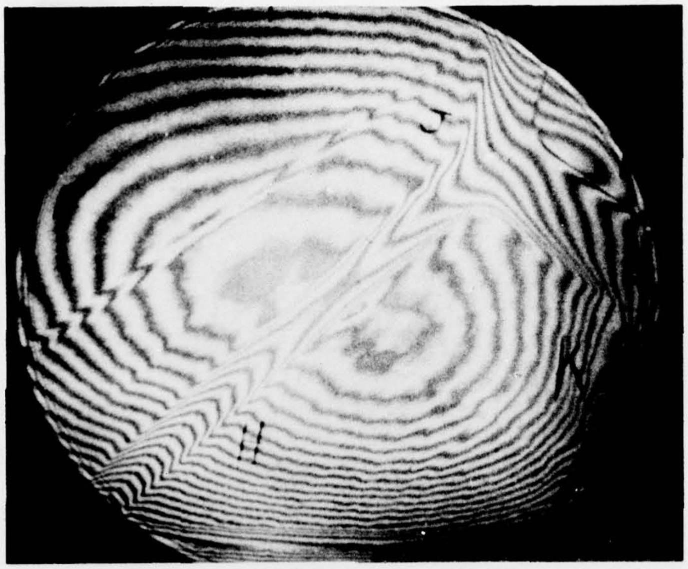
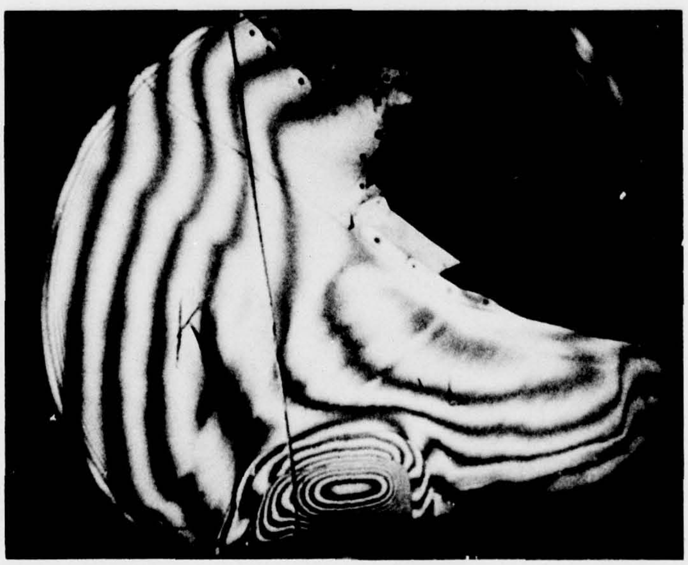


c

Fig A18a-c Wing tip 13 – bottom



d



e

Fig A18d&e

Fig A19a&b

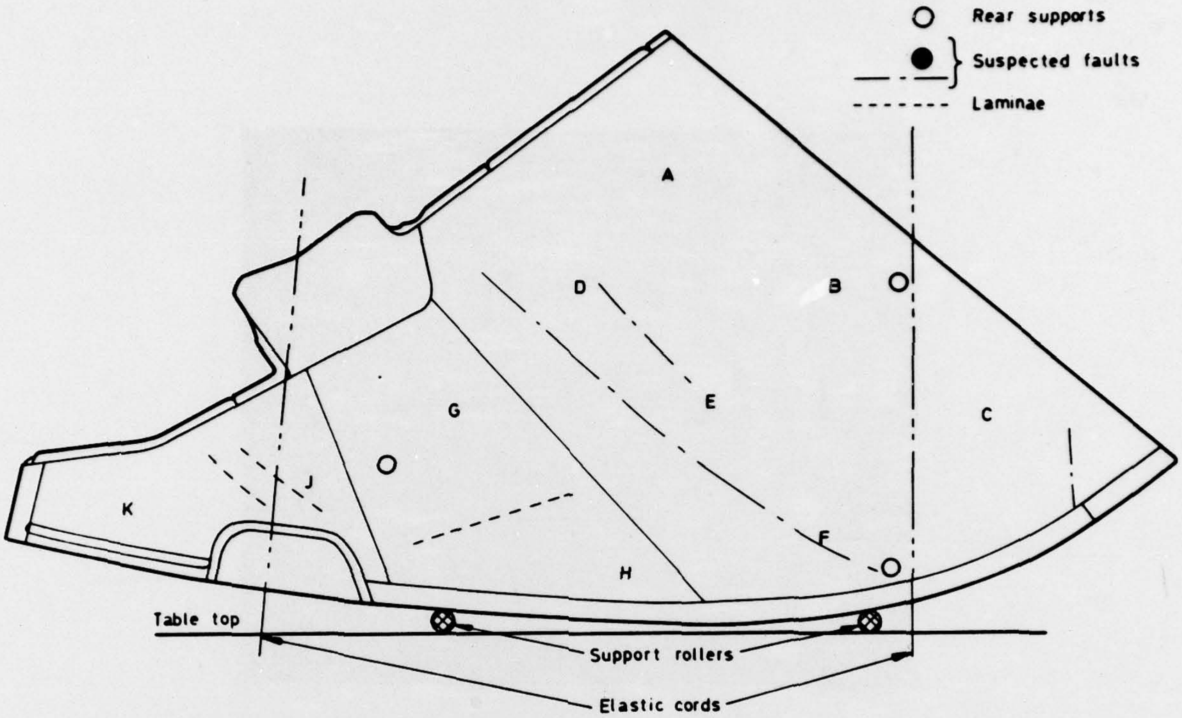


Fig A19a Wing tip 14 — top surface

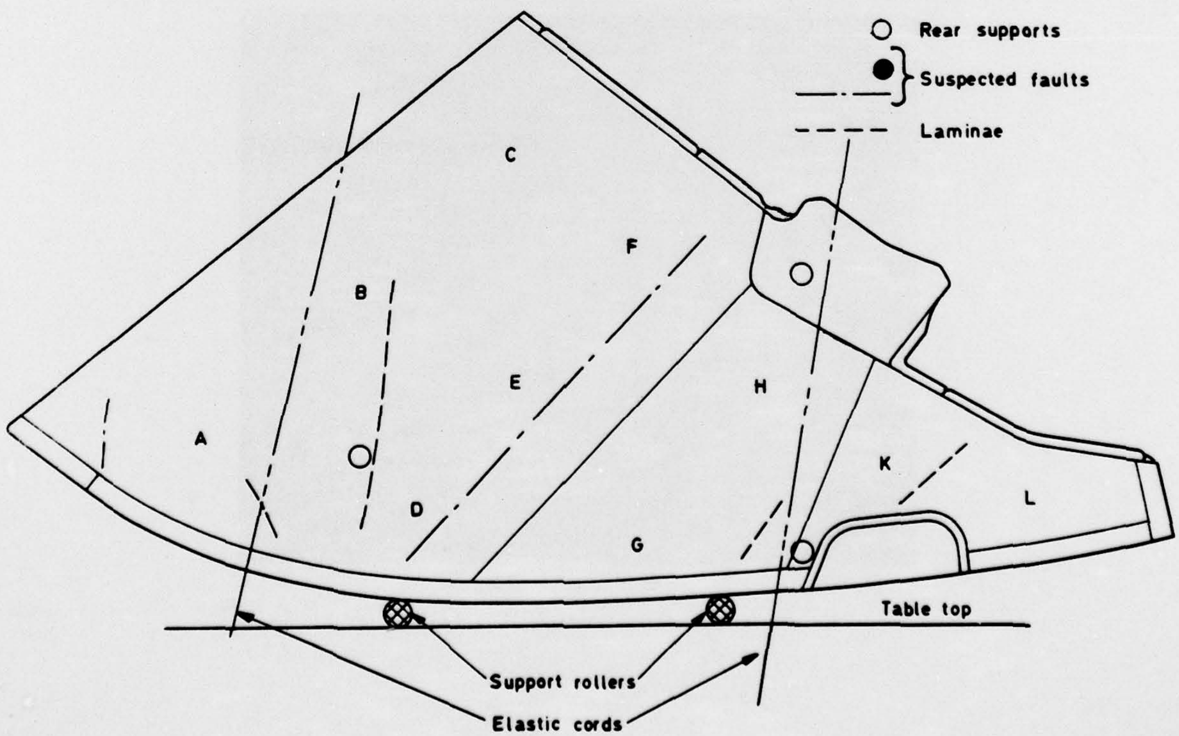
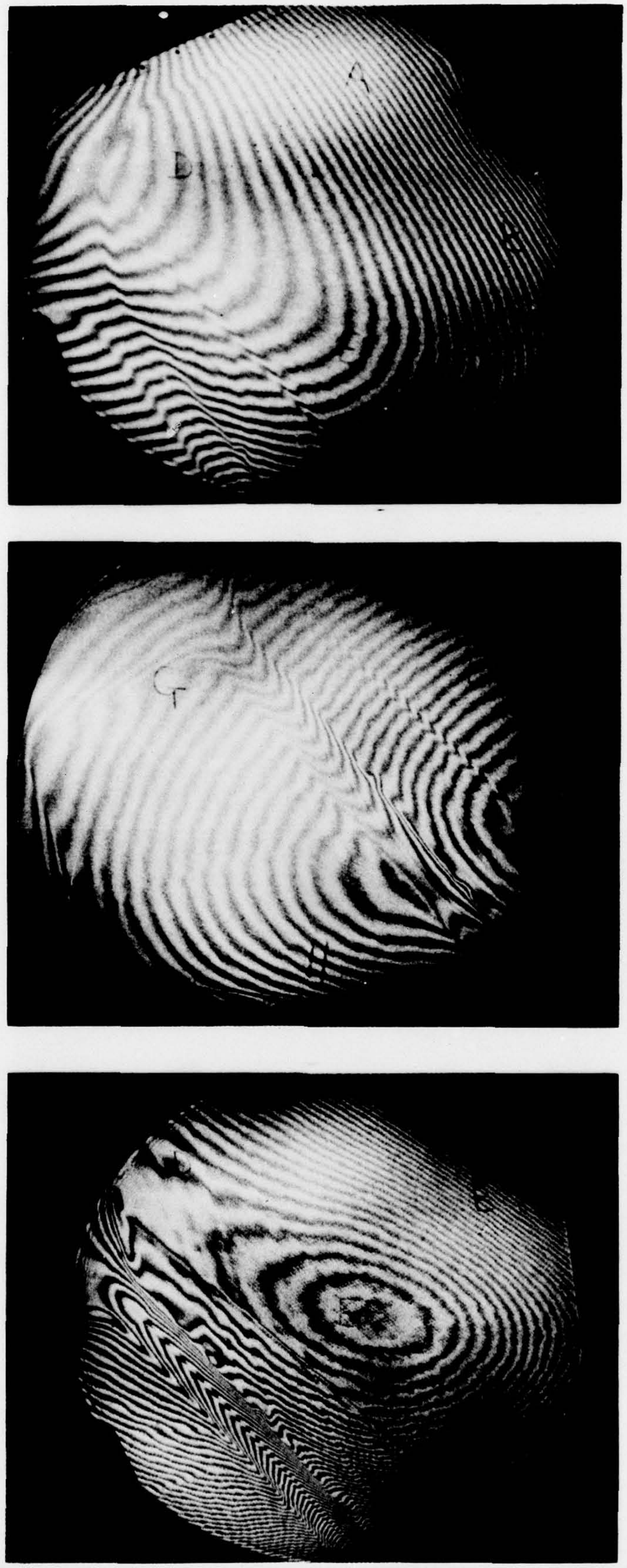


Fig A19b Wing tip 14 — bottom surface

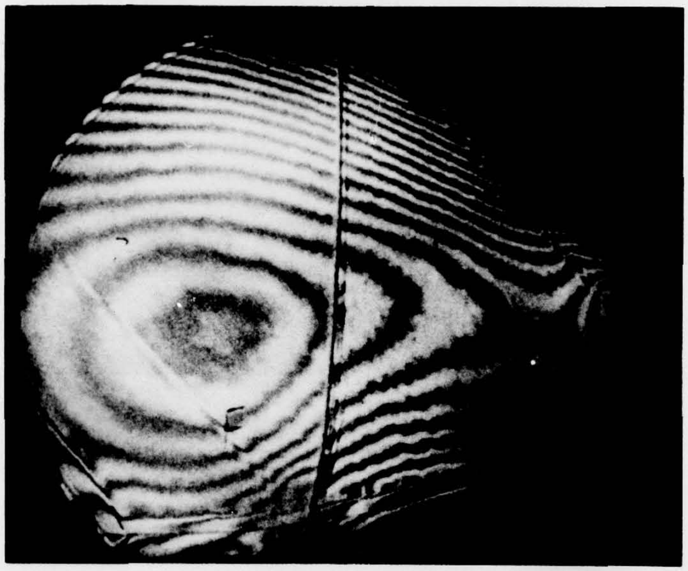


a

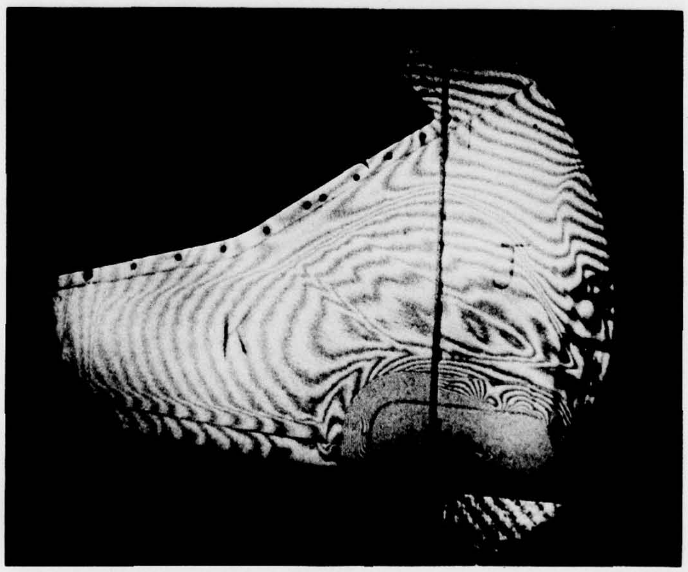
b

c

Fig A20a-c Wing tip 14 – top



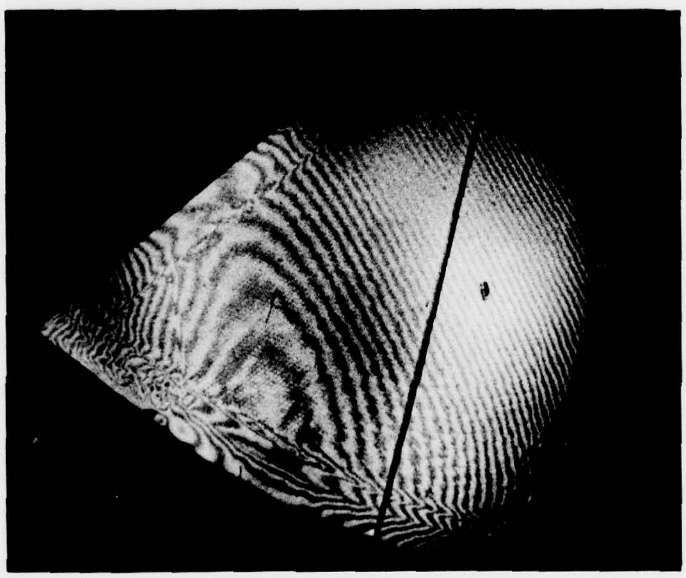
d



e

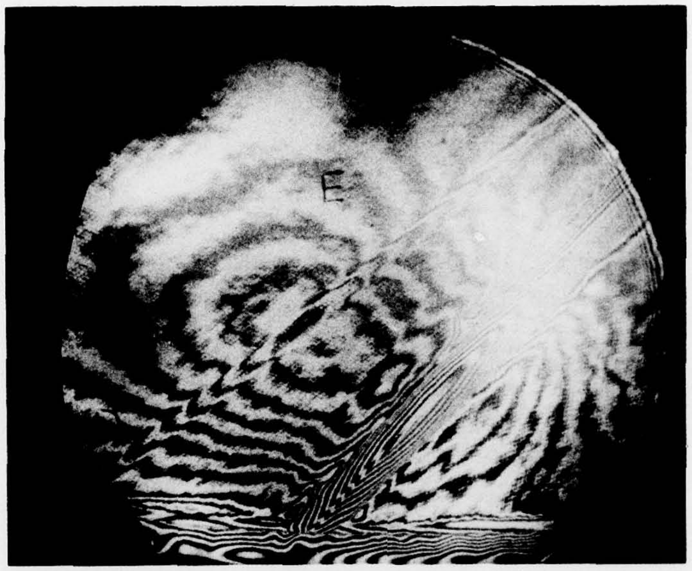
Fig A20d&e

a



b

Fig A21a&b Wing tip 14 – bottom



c

d

Fig A21c&d

REPORT DOCUMENTATION PAGE

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17. Abstract
Holographic interferometry has been used to examine seven experimental Harrier ferry-tips primarily for defects in core to skin bonding. With increasing experience, the quality of the holograms recorded has improved, and although the interference patterns formed when the structure is warmed are often complicated, discontinuities are readily observed. A number of suspected defects have been found which are virtually undetectable using standard radiographic techniques. The most prominent of these are the long straight anomalies visible in all but the first sample examined; it is thought that they may be due to overlapping sheets of film adhesive but this has not yet been established with certainty. An ultrasonic scan of one sample also failed to detect it. Small circular patterns, possibly indicating debonds, have been found in a number of places. A group of large anomalies observed on one sample were confirmed by radiography.